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Part II
Addenda

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Tug Fleet and Ground Operations Schedules and Controls

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TUG FLEET AND GROUND OPERATIONS SCHEDULES AND CONTROLS

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FOREWORD

This final report, submitted in accordance with Data Procurement Document number 480 dated June 1974, contract NAS8-31011, is published in three volumes:

Volume I - Executive Summary (DRL MA-04)

Volume II - Part I Final Report (DRL MA-03)

Part II Addenda (DRL MA-03)

Part III Appendixes (DRL MA-03)

Volume III - Program Study Cost Estimates (DRL MF003M)

The content of each volume is shown in the diagram on the following page.

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TUG FLEET AND GROUND OPERATIONS SCHEDULES AND CONTROLS, FINAL REPORT (NAS8-31011)

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GLOSSARY

A&E	Architectural and Engineering
APS	Auxiliary Propulsion System
C&W	Caution and Warning
CCB	Configuration Control Board
CCMS	Command Control Monitoring System
CDS	Central Data System
CKAFS	Cape Kennedy Air Force Station
COR	Contracting Office Representative
CST	Combined Systems Test
CTMCF	Common Tug Maintenance and Checkout Facility
DA	Double Amplitude
DOD	Department of Defense
EMC/EMI	Electromagnetic Compatibility/Interference
ETR	Eastern Test Range
F/C	Fuel Cell
FCR	Facilities Change Request
FECP	Facilities Engineering Change Proposal
FIT	Functional Interface Test
FMEA	Failure Modes and Effect Analysis
FWG	Facility Working Group
GSE	Ground Support Equipment
HIM	Hardware Interface Module
H.P.	High Pressure
I/F	Interface

I/O	Input/Output
IOC	Initial Operational Capability
IUS	Interim Upper Stage
JSC	Johnson Space Center
KPF	Kick Stage Processing Facility
KSC	Kennedy Space Center
LCC	Launch Control Center
L.P.	Low Pressure
LPS	Launch Processing System
LRU	Line Replaceable Unit
MDF	Mate-Demate Fixture
MIC	Management Information Center
MPS	Main Propulsion System
MSFC	Marshall Space Flight Center
MSI	Maintainability Significant Item
MSS/PSS	Mission Specialist Station/Payload Specialist Station
MTBF	Mean Time between Failure
MTBR	Mean Time between Repair
NASA	National Aeronautics Space Administration
NN/D	Non-NASA/DOD
O&M	Operation and Maintenance
OFI	Operational Flight Instrumentation
OIS	Operational Intercommunication System
OLF	Orbiter Landing Field
OMD	Operations Maintenance Documentation

OMI	Operational Maintenance Instruction
OPF	Orbiter Processing Facility
PCR	Payload Changeout Room
P/L	Payload
PMF	Payload Mate Facility
PPR	Payload Processing Room
RFP	Request for Proposal
RMS	Remote Manipulator System
RTG	Radioisotopic Thermal Generator
S&E	Science and Engineering
SAWG	Site Activation Working Group
S/C	Spacecraft
SCF	Satellite (Spacecraft) Control Facility
SGLS	Space Ground Link System
SHE	System Health Evaluation
SPF	Spacecraft Processing Facility
SSPD	Space Shuttle Payload Description
SRT	Supporting Research and Technology
STDN	Space Tracking and Data Network
STS	Space Transportation System
TBD	To be determined
TFP	Tug Processing Facility
TSE	Transportation Support Equipment
VAB	Vertical Assembly Building
VSWR	Voltage Standing Wave Ratio
WBS	Work Breakdown Structure

Addendum 1
Safety Requirements

MCR-74-488
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Addendum 1 January 1975

TUG SAFING REQUIREMENTS AT POSTLANDING

Prepared by

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CONTENTS

1.0 INTRODUCTION

The results of a study to assess the Tug safing requirements at postlanding are presented in this addendum. The study considered the normal (green light) conditions from Orbiter landing to completion of preparations for the next launch. Normal Tug ground turnaround operations include handling and transportation activities and the performance of inspections, tests, and checkout functions. These activities dictate that hazards to ground personnel, the Tug, GSE, facilities, and ecology be reduced to the lowest practical level consistent with program objectives, cost, and schedules.

During flight operations, the Tug contains energy sources that constitute potential hazards but are required for mission accomplishment. These potential hazards have been reduced to an acceptable level for flight operation by design features (safety factors, etc) and by providing for control of energy sources. The Tug safing philosophy, however, must be to eliminate each energy source as soon as practical after the requirement for that energy is fulfilled. Residual energy sources (hazards) must remain under monitor and control. Tug safing, therefore, is actually accomplished incrementally during recovery, reentry, and postlanding operations.

Actions necessary to comply with Tug safing requirements at postlanding are dependent upon the Tug systems status at the time of Orbiter landing. For the purposes of this study, assumptions were made concerning residual hazards present at landing, because Tug safing requirements for retrieval and reentry are the subject of a concurrent study. Based on these assumptions, requirements and actions were developed to reduce the hazard level of the returned Tug to an acceptable level to permit personnel access to accomplish turnaround activities.

2.0 STUDY GROUND RULES AND ASSUMPTIONS

2.1 GROUND RULES

Ground rules for assessment of Tug safing requirements at postlanding follow:

1) Normal baseline functional flow developed in Task 1.0 shall be followed for this study.

2) For normal turnaround operations, hazard levels must be reduced to a level acceptable for personnel access and performance of required activities. It is considered neither essential nor practical to achieve an absolute safe (completely inert) Tug status.

3) Postlanding safing requirements and actions shall be considered in two phases: (a) the ground operations with the Tug in the Orbiter payload bay, and (b) operations after the Tug has been removed from the Orbiter.

2.2 ASSUMPTIONS

Certain assumptions were required to establish a baseline for this study. Safing to the Tug actually begins upon completion of the primary mission of delivery/retrieval of payloads, and progresses incrementally into the ground turnaround operations. Because the postlanding safing requirements are dependent on conditions at landing, assumptions were established concerning prelanding safing actions and the residual potential hazards on landing. These assumptions follow:

1) Prelanding Safing Actions

   a) Main propellant residual liquids are expelled before retrieval.

   b) The Auxiliary Propulsion System (APS) is secured during retrieval operations.

   c) Tug/Orbiter interfaces are reestablished and verified on retrieval.

   d) Tug electrical power requirements are provided by the Orbiter after retrieval.

   e) Fuel cell residual reactants are expelled through the Orbiter interfaces.

   f) All pressurized tanks and systems are adjusted to nominal levels for reentry.

2) Residual Potential Hazards

   a) Chemical energy in the form of residual hydrogen vapor and hydrazine will be present. Liquid hydrogen residuals will have been expelled from the main propellant and fuel cell reactant tanks, but some residual vapor will remain. The APS will be secured by closing the series redundant thruster valves with residual hydrazine in the tank and lines.

b) Pressure energy will be present in the main propellant tanks, fuel cell reactant tanks, and pressurization systems. The main propellant and fuel cell tanks will be pressurized to preclude implosion during landing. The pressurization systems will contain residual pressurants. These pressures will vary as a function of temperature changes during and after landing.

c) The partially discharged auxiliary (flight) battery presents an electrical energy source.

d) Since no ordnance devices have been identified in the baseline configuration, safing requirements for ordnance systems have been excluded from consideration at this time.

3.0 SUMMARY OF RESULTS

In accordance with study ground rules, safing requirements at postlanding were developed for the following two phases of ground operations.

3.1 ORBITER/TUG OPERATIONS

The safing requirements during Orbiter/Tug (Tug in Orbiter payload bay) operations may be discussed in three functional areas.

1) Since the Orbiter flight crew has prime responsibility to monitor and control safety-critical Tug functions, they shall make a final check before egress to ensure all Caution and Warning (C&W) parameters are within limits. The flight crew shall also initiate and verify transfer of control of Tug functions to Ground Control crews.

2) Tug Ground Control shall monitor the C&W parameters with particular attention to tank pressure levels during postlanding temperature variations. In the course of monitoring tank pressures and temperatures, Ground Control shall verify the pressure integrity of all tanks (in the gross terms available) with flight instrumentation.

3) The Orbiter Ground Operations crew shall establish the payload bay purge to neutralize any hazardous vapors. The exhaust from the payload bay purge shall be subjected to hazardous vapor detectors to ensure freedom from leaks. In the event the hydrogen tanks require venting, the Tug H_2 vent shall be connected to a burn stack through Orbiter interfaces.

Compliance with these requirements will provide confidence that the Tug may be removed from the Orbiter payload bay and transported to the TPF safely.

3.2 TUG TURNAROUND OPERATIONS

Tug safing for turnaround operations is completed after removal from the Orbiter payload bay and transport to the TPF. Four requirements reduce hazards to an acceptable level for turnaround activities.

1) The APS tanks and lines shall be drained of residual liquid hydrazine. The system shall then be purged and sealed with a dry nitrogen blanket.

2) The auxiliary (flight) battery shall be disconnected and removed from the Tug.

3) All Tug pressurized systems shall be leak checked with helium at maximum operating pressure to verify all systems' integrity. Upon completion of the leak check, each system shall be vented to a pressure of one-fourth or less of the design burst pressure and sealed. Hydrogen systems shall be vented to a burn stack for disposal of any residual hydrogen vapor during this operation. This reduced blanket pressure will remain in the tanks during the remainder of the processing flows.

4) Pressure systems shall be monitored by LPS during turnaround activities to ensure that pressure levels remain in limits. Continuous monitoring is not required because pressure changes are a function of temperature change and the Tug is in a controlled environment during turnaround. A temperature change of 30°F would produce a pressure change in the order of 1.0 psia on the largest (hydrogen) tank.

4.0 DISCUSSION

Detailed assessments of each identified Tug postlanding potential hazard follow:

4.1 CHEMICAL ENERGY

The two sources of potentially hazardous chemical energy present are hydrazine and hydrogen.

4.1.1 Hydrazine

The major chemical energy source remaining onboard the Tug at landing will be the residual hydrazine liquid in the APS tanks and lines. Hydrazine, N_2H_4, is a stable liquid when confined in a system. It is not sensitive to shock, friction, or temperature extremes below 320°F. Hydrazine vapor is toxic (threshold limit value of 1 ppm) and flammable (or explosure) at concentrations above 4.7% by volume.

The APS system will be in a sealed condition with series redundant thruster valves closed during reentry and landing. Because leaks could develop from stresses imposed at landing, a nitrogen purge of the payload bay and hydrazine vapor detection should be initiated upon arrival at the OPF. Absence of hydrazine vapor will indicate that the APS is safe for Tug removal and transport to the TPF airlock. The liquid hydrazine may then be removed, using protective clothing for fuel handlers, and the system purged with dry nitrogen. The system can then be sealed with a nitrogen blanket and then proceed through the turnaround cycle with an acceptable hazard level.

4.1.2 Hydrogen

It has been assumed that the liquid hydrogen (LH_2) has been removed from the main propellant tank and the fuel cell reactant tank before reentry, but a relatively high concentration of H_2 vapor remains. This assumption is based on a previous study which shows that, when the LH_2 is dumped, the tank pressure would be bled to $\approx$ 2.0 psia (well above the triple point pressure of 1.0 psia for hydrogen), which should preclude the formation of H_2 ice in the tank. H_2 vapor is not toxic but is highly flammable in concentrations above 4% by volume in air. Vapors within the flammability limits can be ignited with very low energy, including self-generated static electricity, and present explosion hazards when partially confined.

The systems will be sealed before reentry, but leaks could develop during landing. A nitrogen purge of the payload bay and hydrogen vapor detection should therefore be established upon arrival at the OPF. During the Orbiter/Tug ground operations, Tug Ground Control will monitor tank pressures and perform a pressure integrity check (in the gross terms available) with flight instrumentation. Absence of hydrogen vapor and a successful integrity check will provide confidence that the hydrogen systems are safe for Tug removal and transport to the TPF airlock. All pressure systems will be leak checked at operating pressure in the TPF, which will verify system integrity. The system will then be vented to a safe level, as discussed in paragraph 3.2, and sealed for the remaining turnaround activities. The venting of the H_2 system must be through a burn stack because the vented gases may be above the lower flammability limit. The hydrogen vapor sealed in the pressure tight system is considered an acceptable hazard level with minimum impact on turnaround timelines and purge commodity costs, especially helium.

4.2 PRESSURE ENERGY

Tug pressurization systems will contain residual pressurants, and propellant/fuel cell reactant tanks will be pressurized at landing. These pressures can be controlled by venting or adding pressure to the propellant/fuel cell reactant tanks, as required. The propellant/reactant tanks pressure level will be sufficient to preclude implosion during reentry and landing. Pressure levels in all systems will vary as a function of temperature changes during the landing and postlanding period and must be maintained within design limits. Safety requirements at postlanding, then, are for the Orbiter flight crew to monitor, verify that pressures are within limits after landing, and ensure that control is transferred to Tug Ground Control for continuation of the monitor/control function. After the postlanding cooldown is completed, tank pressure will stabilize, and continuous monitoring is not required. Temperature variations of 30°F will produce a pressure change of only 1.0 psia in the largest tank.

Before the Orbiter payload bay doors are opened, the Tug pressure systems will be vented, if required, to provide safety factors of 2 from design burst levels. The Tug is then removed from the Orbiter and transported to the TPF where a leak check at operating pressure with helium is performed. Upon completion of the leak check, all systems will be vented to provide safety factors of 4 from design burst. The pressure systems are then safe for personnel access for the remainder of the turnaround activities.

4.3 ELECTRICAL ENERGY

The partially discharged Tug battery is also a potential hazard at postlanding. Because the probability of a hazardous malfunction is very low, the battery may be treated routinely in the TPF. Disconnecting and removal of the battery will eliminate this potential hazard from further consideration.

Addendum 2 Mate/Demate

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Addendum 2 January 1975

TUG/SHUTTLE MATING/
DEMATING FUNCTIONS
AND CONSTRAINTS

Prepared by

F. L. Whitney,
Systems Integration

CONTENTS

1.0 INTRODUCTION

The Tug and its spacecraft-to-Orbiter interface is of prime interest and concern to ground operations analysis. For the Space Transportation System (STS) to meet its objective of a cost effective system, the Tug design being considered must incorporate definite constraints imposed by the Orbiter, while at the same time the Orbiter must incorporate those interfaces required to support a Tug and its payload. For the STS to meet this objective, the Tug/Shuttle interface and its associated ground operational impact should be periodically analyzed so that any design impact may be incorporated into the systems as early as possible.

This special emphasis assessment is limited to the Tug/Shuttle mating/demating functions and constraints of the total interface concern. The assessment is based on the Tug-to-Shuttle physical and functional interfaces as defined in the following documents:

Baseline Space Tug Requirements and Guidelines, MSFC 68M00039-1

Baseline Space Tug Definition, MSFC 68M00039-2

Baseline Space Tug Ground Operations, Verification Analysis and Processing, MSFC 68M00039-4

Space Shuttle System Payload Accommodations, JSC 07700, Vol XIV, Rev C

In addition to the above documentation, any pertinent information generated during the assessment phase from the Program Development Space Tug Task Team and/or MSFC will be factored into the analysis.

2.0 GROUND RULES/ASSUMPTIONS

2.1 GROUND RULES

Tug/Shuttle mating/demating functions were limited to those activities performed before liftoff and after safing the Orbiter on landing. The relative location of interfaces with respect to the Orbiter are shown in Figure 2-1. All others were considered mission operations.

The interfaces considered were:

1) payload (Tug/Spacecraft/Adapter) installation;

2) payload removal;

3) T-0 launch umbilical panels;

4) prelaunch umbilical panel;

5) payload retention system;

6) remote manipulator system;

7) aft flight deck payload operation equipment;

8) payload to aft bulkhead interface;

9) payload to forward bulkhead interface;

10) aft flight deck to aft bulkhead wiring;

11) payload primary power panel;

12) Tug tilt pivot attach point (Sta 1293).

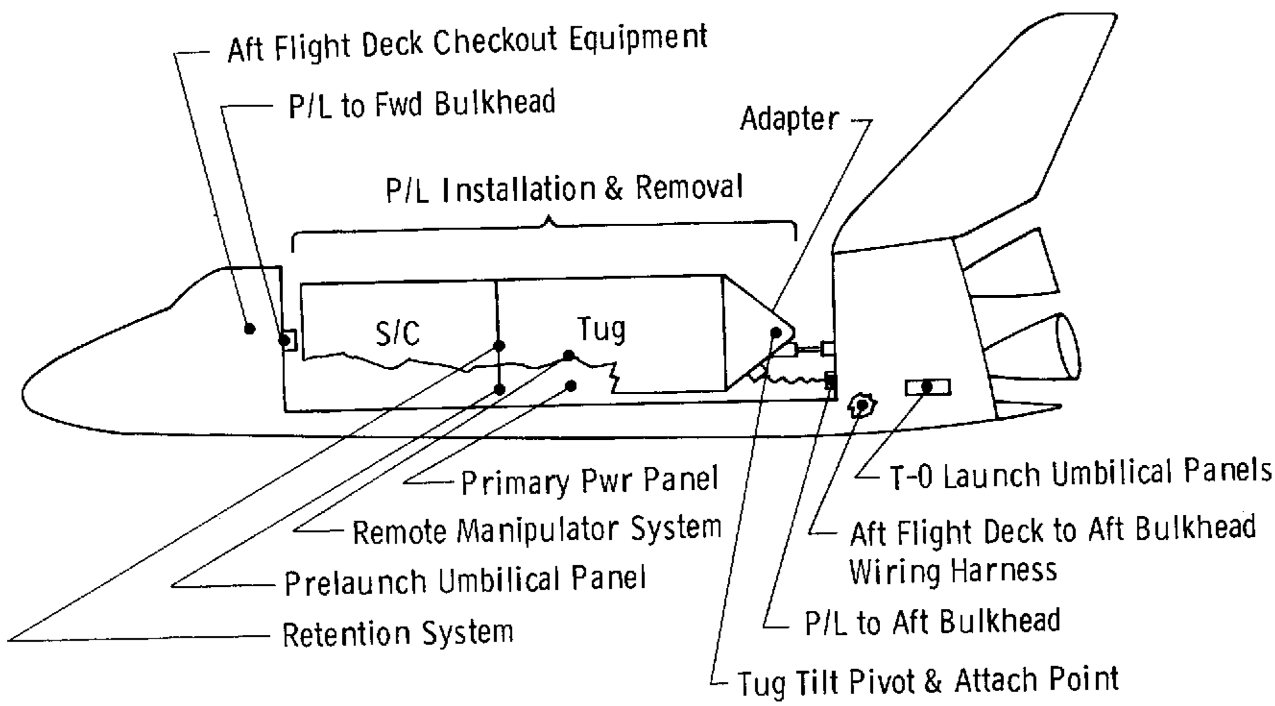

Figure 2-1 Payload Mate/Demate Interfaces

2.2 ASSUMPTIONS

1) A payload changeout room (PCR) with a payload manipulator system, or equivalent, will be available for payload installation at the pad.

2) The PCR will be capable of maintaining a seal with the Orbiter for a common environment.

3) The PCR will contain access space to verify Tug-to-retention system alignment during the mating function.

4) Access will be available at the aft bulkhead and adapter interface area.

5) If the aft bulkhead and adapter interface is expanded to include linear deployment aids, retention system for flexible connectors, etc, the impact on ground operations must be reevaluated.

6) Payload wiring from aft flight deck to aft bulkhead interface is adequate without field installed capability.

7) It is an Orbiter function to verify the interface integrity from the T-0 umbilicals to the aft bulkhead interface and aft flight deck standard wiring to aft bulkhead.

8) The aft flight deck monitor and control equipment (flight unit) will be functionally verified with the payload, by the payload, before installation in the Orbiter.

9) Payload primary power panel is used for a nondeployable payload.

3.0 SUMMARY OF RESULTS

Detailed and conceptual design data have not matured sufficiently to determine total impact on Tug/Shuttle mating/demating ground operations. However, based on the ground rules and assumptions of paragraph 2.0 herein, the following conclusions and recommendations can be made and should be considered for advance planning:

1) The payload retention system does not currently have an attach point at Sta 1293.0.

2) The Tug does not have handling lugs for installation and removal.

3) The adapter attach point (tilt pivot point) will have to be inhibited from the remote latching system during deployment and reinstated for payload removal.

4.0 DISCUSSION

A function flow defining the Tug/Shuttle mating/demating activities, including PCR/Tug mating, is depicted in Figure 2-2. Each interface is discussed below as analyzed for Ground Operation impact.

4.1 PAYLOAD (TUG/SPACECRAFT/ADAPTER) INSTALLATION

During the course of this assessment, the payload was assumed to interface with the PCR from the bottom to accommodate vertical payload installation (baseline flow). It was also assumed that a hoist would retract the payload from the canister, and a payload manipulator was capable of transferring the payload from the hoist to the manipulator arms, and installing the payload in the Orbiter bay retention system. This concept has no impact, providing the canister can accommodate vertical hoisting, i.e., end extraction capability with guide rails, and the PCR can be sufficiently sealed with the Orbiter for a common clean environment. Whether the vertical or horizontal payload installation concept is employed, the payload must have the capability for manipulator arm and/or horizontal handling adapter attachment while inserting and transferring the payload into the retention system. This capability would require flight type, hard points on the payload, or GSE removable handling lugs.

4.2 PAYLOAD REMOVAL

The same comments for transfer of the payload, (para 4.1) apply for payload removal. In addition, depending on Tug and/or spacecraft design, it is foreseeable that the capability must exist for retaining a minimum power level on the busses. This would particularly be true of an onboard computer system that would lose memory and/or issue random discretes during a zero power condition. This could result in an unsafe payload during the removal process. A possible solution would be a battery charging capability from the Orbiter to the payload batteries. Having this capability would also eliminate some spacecraft trickle charge GSE requirements during the final countdown phase.

During the payload removal process, the GSE handling equipment must be adjusted to coincide with the payload cg. It is conceivable that on some return flights, i.e., aborts and retrieval missions, the cg will have to be preestablished by analysis. This data may be flight data, ascertained by the Orbiter in the case of an abort, and/or the ground control station in the case of a retrieval mission. The techniques, methodology, and data requirements will need preplanning (before Orbiter landing and safing) so that payload removal will not impact the baseline flow and timeline.

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4.3 T-0 LAUNCH UMBILICALS

There were no apparent problems identified with the T-0 Launch Umbilical concept. It was assumed that the Orbiter would verify the integrity of the umbilicals from the panel to the aft bulkhead.

4.4 PRELAUNCH UMBILICAL

Baseline Tug documentation does not define an interface connector for the prelaunch umbilical panel. However, this umbilical may be required when the spacecraft is defined.

4.5 PAYLOAD RETENTION SYSTEM

There were no apparent problems identified with the payload guides and remote latching system concept. As presently designed, i.e., with the adapter tilt pivot point, the same as a latching point, the remote latch will need to be inhibited during deployment and reinstated for payload removal.

4.6 REMOTE MANIPULATOR ARM

This interface was not assessed because it was considered to be a mission operation function.

4.7 AFT FLIGHT DECK PAYLOAD OPERATION EQUIPMENT

The monitor and control equipment interface (MSS/PSS/Orbiter/Payload) was assumed to be compatible. In accordance with the baseline flow, during the Functional Interface Test (FIT) the actual flight MSS/PSS consoles will be functionally verified with the payload using an orbiter wiring harness simulator. The MSS/PSS consoles will then be installed in the orbiter at the OPF.

4.8 PAYLOAD TO AFT BULKHEAD INTERFACE

All defined Tug-related electrical and fluid umbilicals pass through the Tug adapter to the aft bulkhead. The current deployment concept requires these umbilicals (adapter/aft bulkhead) to remain engaged for the duration of a Tug roundtrip mission. A common problem for any concept will be access to verify the integrity of the interface during and after mate. This problem is compounded when (1) a flexible line concept is considered because a retention system will probably be required to retain the lines during mating condition; (2) deployment aids are being considered to rotate the payload out of the Orbiter Bay; and (3) a remotely controlled retractable plate will require visual aids for mating and demating.

This concept results in poor accessibility for both the horizontal and vertical payload installation and removal.

4.9 PAYLOAD TO FORWARD BULKHEAD INTERFACE

Baseline Tug documentation does not define an interface requirement for this location.

4.10 AFT FLIGHT DECK TO AFT BULKHEAD WIRING

It is assumed that the standard wiring harness from the MSS/PSS consoles is adequate. A requirement to provide a payload peculiar wiring harness has not been identified.

4.11 PAYLOAD PRIMARY POWER PANEL

Tug baseline documentation does not define an interface at this umbilical panel.

4.12 TUG TILT ATTACH POINT (STA 1293)

The current Tug tilt point at Sta 1293 is not a standard load carrying retention point in accordance with the Space Shuttle System Payload Accommodation document.

Addendum 3 Access Provisions

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TUG ACCESS PROVISION
BEFORE PRELAUNCH

Prepared by

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CONTENTS

Table

1.0 INTRODUCTION

This study/analysis includes several definitions of the term "access" and spans the various phases of Tug processing. The Access is defined as (1) physical access related to changeout of line replaceable units (LRUs), (2) functional access for verification of replaced LRUs and accomplishment of subsystem/system health checks and monitoring, and (3) service access for loading required mission consumables and safing at Tug retrieval and before Tug refurbishment.

2.0 STUDY GROUND RULES AND ASSUMPTIONS

1) Refurbishment and unscheduled maintenance shall be limited to LRUs for the purpose of this study. Hardware items considered in this category are delineated in Table 3-1. Software items are considered replaceable by means of normal communications at any time up to and during launch and orbit, and therefore will not be considered a part of this study.

2) No maintenance (replacement of LRUs) shall be accomplished after Tug/payload is installed in the Orbiter payload bay. However, access of a functional or service nature will be required. Physical access should be provided for up to this installation point to include changeout of LRUs at payload changeout room (PCR) assuming reverification capability is provided at that location.

3) Total Launch Processing System (LPS) capability shall be available to Tug/payload up to a minimum of T-0 or later in the countdown to provide total Tug/payload checkout.

4) This study is based on the configuration definition contained in MSFC documentation 68M00039-2, dated July 15, 1974, entitled "Baseline Space Tug Configuration Definition," and MSFC 68M00039-4, dated July 15, 1974, entitled "Baseline Space Tug Ground Operations, Verification, Analysis, and Processing."

3.0 SUMMARY OF RESULTS

During the course of this study, various access provisions (physical, functional, and servicing) were evaluated based on conceptual design data currently available. In general, four physical access problems were detected relating to the LH_2 submerged valves, the helium spheres located in the intertank region, the LO_2 capacitive mass probe, and the APS hydrazine spheres. One functional access problem related to post-Orbiter installation interface verification and one servicing access problem related to fuel cell reactant loading were found.

3.1 PHYSICAL ACCESS PROBLEMS

Details relating to the four problems are contained in para 4.1.1, 4.1.2, 4.1.3, and 4.1.4, respectively. Two alternative design solutions to alleviate the problems are (1) increase the access door size in the intertank region to approximately 36x36 in. and the addition of an access hatch in the aft end of the LH_2 tank and the LO_2 tank, or (2) increase forward hatch size.

3.2 FUNCTIONAL ACCESS PROBLEM

Details relating to this problem are contained in para 4.2.2.1. The problem requires addition of monitoring switches to verify connect/disconnect of umbilicals and Tug mounting points that are not visually accessible for mating interface inspection.

3.3 SERVICE ACCESS PROBLEM

Details relating to this problem are contained in para 4.2.3.1. The problem involves the addition of servicing connections at the Orbiter interface for fuel cell reactant loading and topping.

3.4 ADDITIONAL RECOMMENDATIONS

During performance of this study, it was further noted that by rearrangement of selected LRUs, the refurbishment and checkout could be accomplished on a modular basis that would shorten and simplify the turnaround requirements. The modular approach would develop the Tug into avionics and propulsion modules, and would require the relocation of avionics LRU and the active thermal control system from the intertank region to the forward skirt. This approach, however, could have some disadvantages.

4.0 TUG/PAYLOAD ACCESS PROVISIONS

4.1 PHYSICAL ACCESS PROVISION

This portion of the study was primarily directed toward replacement of LRUs, and the adequacy of defined existing physical access provisions, with consideration given to man/machine relations and GSE requirements to support the changeout and verification/reverification task. It was necessary to perform additional analysis in order to arrive at a probable list of LRUs that would be contained in the Space Tug. Table 3-1 lists those LRUs that were evident from the limited data available at this time. Further, it was an objective of this study to provide identification of potential design problems and recommended solutions.

Adequacy of physical access provision is dependent on several major concerns related to the individual hardware item, such as redundancy, mission criticality, size, weight, and Tug processing phase. Table 3-1 shows the Physical Access Evaluation with items judged critical discussed in subsequent paragraphs. An asterisk (*) by a "TBS" indicates exact physical characteristics are unknown.

4.1.1 LH_2 Horizontal Dump Valves and Fill, Drain, and Prevalve

Although valves may exist that are LH_2 compatible, these particular valves will be required to last for 20 missions. It is highly possible that in this severe thermal environment performance degradation can be expected. Therefore, serious consideration must be given to making these valves more accessible by inclusion of a removable hatch cover in the near vicinity of valve mounting locations. The problem is further compounded by lack of redundancy of these critical components. Possible solutions are to add the aforementioned access provision in the intertank region, or provide periodic replacement that would require additional GSE to gain access into the tank via forward dome cover. This cover would also require an increase in size. The former is the preferred solution. It should be noted that the problem also exists with the LH_2 vertical and horizontal vent valves.

4.1.2 Helium Sphere Intertank Region

Access door located at Sta 1128 is 30 inches square, whereas the helium sphere has an approximate diameter (based on defined volume) of 29 inches. This condition would not allow clearance for handling equipment in the event that a problem in the sphere required its removal. This then would require that the Tug be separated at the optional field splice, Sta 1061.74, which would be costly and time consuming. It is, therefore, recommended that the access door is increased to 36 inches square.

Table 3-1 Physical Access Evaluation

SYSTEM	ITEM	LRU HARDWARE DESCRIPTION / PHYSICAL DATA	DIMENSION (INCHES)	WEIGHT (POUNDS)	TUG LOCATION	TUG ACCESS	BASELINE GSE DEFINITION	LEGEND: S=STRUCTURES P=PROPULSION T=THERMAL CONT. A=AVIONICS REMARKS/NOTES
S	1	Docking Mech.	TBS*	230.0	Fwd. Skirt	Adequate	Adequate	Note 5
	2	LH_2 Aft Support	1.75 dia x TBS	2.9	Intertank	Adequate	Adequate	Note 1
	3	LO_2 Aft Support	2.00 dia x TBS	1.6	Aft Skirt	Adequate	Adequate	Note 2
	4	Latching Mech.	TBS*	10.6	Aft Adapt.	Adequate	Adequate	Note 3
	5	Thrust Structure	91 dia x 28.5 x 7 dia	24.8	Aft Skirt	Adequate	Adequate	Note 2, with main engine removed
P	1	Main Engine	70.6 dia x 110	442	Aft Skirt	Adequate	Adequate	Note 2
	2	(F&D) Solenoid Cont Valve	TBS*	TBS*	Intertank/ Aft Skirt	Adequate	Adequate	Notes 2 & 4
	3	LH_2 Dump Valve	TBS	TBS	LH_2 Tank	Inadequate	Inadequate	See para. 4.1.2
	4	LH_2 Fill and Drain & Prevalve	TBS	TBS	LH_2 Tank	Inadequate	Inadequate	See para. 4.1.2
	5	LH_2 Fill & Drain Valve	TBS*	TBS*	Aft Skirt	Adequate	Adequate	Note 2
	6	LH_2 Coupler	TBS*	TBS*	Aft Adapt	Adequate	Adequate	Note 3
	7	LH_2 Flex Line	TBS*	TBS*	Aft Adapt	Adequate	Adequate	Note 3
	8	LH_2 Quick Disconnect	TBS*	TBS*	Aft Skirt	Adequate	Adequate	Note 2
	9	LH_2 Vert. Vent Valves	TBS	TBS	LH_2 Tank	Inadequate	Inadequate	Similar to para. 4.1.2
	10	LH_2 Horizontal Vent	TBS	TBS	LH_2 Tank	Inadequate	Inadequate	Similar to para. 4.1.2
	11	LH_2 Thermodynamic Vent	TBS*	13.0	LH_2 Tank	Adequate	Adequate	Note 4

Table 3-1 (cont)

SYSTEM	ITEM	PHYSICAL DATA / LRU HARDWARE DESCRIPTION	DIMENSION (INCHES)	WEIGHT (POUNDS)	TUG LOCATION	TUG ACCESS	BASELINE GSE DEFINITION	LEGEND: S=STRUCTURES P=PROPULSION T=THERMAL CONT. A=AVIONICS / REMARKS/NOTES
	12	LO_2 Fill, Drain & Dump Valve	TBS*	TBS*	Intertank or Aft Skirt	Adequate	Adequate	Notes 1 & 2
	13	LO_2 Prevalve	TBS*	TBS*	Intertank or Aft Skirt	Adequate	Adequate	Notes 1 & 2
	14	LO_2 Coupler	TBS*	TBS*	Aft Adapt.	Adequate	Adequate	Note 3
	15	LO_2 Flex Line	TBS*	TBS*	Aft Adapt.	Adequate	Adequate	Note 3
	16	LO_2 Quick Disconnect	TBS*	TBS*	Aft Skirt	Adequate	Adequate	Note 2
	17	(Vent) Solenoid Cont. Valve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	18	(Vent) LO_2 Vent Valve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	19	LO_2 Thermodynamic Vent	TBS*	13.0	LO_2 Tank	Adequate	Adequate	Note 1
	20	Helium Sphere	29 dia	TBS	Intertank/ Aft Adapt.	Marginal	Adequate	Notes 1 & 3, see para. 4.1.3
	21	Solenoid Cont. Valve	TBS*	TBS*	Intertank/ Aft Skirt & Aft Adapt.	Adequate	Adequate	Notes 1, 2 & 3
	22	Helium Regulator	TBS*	TBS*	Intertank/ Aft Adapt.	Adequate	Adequate	Notes 1 & 3
	23	Filter Assembly	TBS*	TBS*	Intertank/ Aft Adapt.	Adequate	Adequate	Notes 1 & 3
	24	Helium Vent Valve	TBS*	TBS*	Intertank/ Aft Adapt.	Adequate	Adequate	Notes 1 & 3

Table 3-1 (cont)

SYSTEM	ITEM	LRU HARDWARE DESCRIPTION / PHYSICAL DATA	DIMENSION (INCHES)	WEIGHT (POUNDS)	TUG LOCATION	TUG ACCESS	BASELINE GSE DEFINITION	LEGEND: S=STRUCTURES P=PROPULSION T=THERMAL CONT. A=AVIONICS REMARKS/NOTES
	25	Helium Quick Disconnect	TBS*	TBS*	Aft Adapt	Adequate	Adequate	Note 3
	26	Helium Coupler	TBS*	TBS*	Aft Adapt	Adequate	Adequate	Note 3
	27	Actuator Assembly	TBS*	TBS*	Aft Skirt	Adequate	Adequate	Note 2
	28	Main Pump	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	29	Auxiliary Pump	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	30	Check Valve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	31	Solenoid Seq. Valve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	32	Hi. Press. Relief Valve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	33	Lo Press. Relief Valve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	34	Bleed Valve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	35	Filter	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	36	LO_2 Capacitive Mass Probe	TBS	TBS	LO_2 Tank	Inadequate	TBS	See Para 4.1.4
	37	LH_2 Capacitive Mass Probe	TBS*	TBS*	LH_2 Tank	Adequate	Adequate	Note 5
	38	LO_2 Control Assy.	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	39	LH_2 Control Assy.	TBS*	TBS*	Fwd. Skirt	Adequate	Adequate	Notes 4 & 5
	40	Power Supply	TBS*	TBS*	Fwd. Skirt	Adequate	Adequate	Notes 4 & 5
	41	Point Level Sensors	TBS*	TBS*	LH_2 & LO_2 Tanks	Inadequate	TBS	Note 5, similar to para 4.1.4

Table 3-1 (cont)

SYSTEM	ITEM	LRU HARDWARE DESCRIPTION / PHYSICAL DATA	DIMENSION (INCHES)	WEIGHT (POUNDS)	TUG LOCATION	TUG ACCESS	BASELINE GSE DEFINITION	LEGEND: S=STRUCTURES P=PROPULSION T=THERMAL CONT. A=AVIONICS REMARKS/NOTES
	42	APS Motor Assy.	30 x 30 x TBS	50.0	Intertank	Adequate	Adequate	Note 1
	43	Solenoid Fuel Valve	TBS*	TBS*	APS Assy.	Adequate	Adequate	Note 1
	44	Solenoid Fuel Prevalve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	45	Filter	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	46	N_2H_4 Press. Guage	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	47	N_2H_4 Fill Q.D.	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	48	N_2H_4 Vent Q.D.	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	49	N_2H_4 Sphere	32 dia	TBS	Intertank	Inadequate	Adequate	See para 4.1.5
	50	Helium Vent Valve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	51	Helium Press. Guage	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	52	Helium Regulator	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	53	Helium Sphere	29 dia	TBS	Intertank	Inadequate	Inadequate	Same as para 4.1.3
	54	Helium Q.D.	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
T	1	Elect. Heater	TBS*	TBS*	Fwd. Skirt	Adequate	Adequate	Notes 4 & 5
	2	Freon Accum.	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	3	Freon Fill Valve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	4	Freon Pump	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1

Table 3-1 (cont)

SYSTEM	ITEM	LRU HARDWARE DESCRIPTION / PHYSICAL DATA	DIMENSION (INCHES)	WEIGHT (POUNDS)	TUG LOCATION	TUG ACCESS	BASELINE GSE DEFINITION	LEGEND: S=STRUCTURES P=PROPULSION T=THERMAL CONT. A=AVIONICS REMARKS/NOTES
	5	Dryer Assembly	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	6	Filter	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	7	Filter Bypass Valve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	8	Heat Exchanger	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	9	Radiator	24 x 48 x TBS	TBS	Intertank	Adequate	Adequate	Note 1
	10	Selector Valve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	11	Flow Control Valve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	12	Temp. Sensor	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	13	Helium Cont. Valve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	14	Helium Regulator	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	15	Helium Vent Valve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	16	Heat Pipe	½ x ½ x 120	TBS	Intertank/ Fwd. Skirt	Adequate	Adequate	Notes 1, 4 & 5
	17	Thermal Splice	TBS*	TBS*	Intertank/ Fwd. Skirt	Adequate	Adequate	Notes 1, 4 & 5
	18	LH_2 Purge Press. Reg.	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	19	LO_2 Purge Press. Reg.	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	20	LH_2 Purge Cont. Valve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	21	LO_2 Purge Cont. Valve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1

Table 3-1 (cont)

Table 3-1 (cont)

SYSTEM	ITEM	LRU HARDWARE DESCRIPTION / PHYSICAL DATA	DIMENSION (INCHES)	WEIGHT (POUNDS)	TUG LOCATION	TUG ACCESS	BASELINE GSE DEFINITION	LEGEND: S=STRUCTURES P=PROPULSION T=THERMAL CONT. A=AVIONICS / REMARKS/NOTES
	22	LH_2 Purge Vent Valve	TBS*	TBS*	Intertank	Adequate	Adequate	Note 1
	23	LO_2 Purge Vent Valve	TBS*	TBS*	Aft Skirt	Adequate	Adequate	Note 2
	24	Radiation Shield	TBS	TBS	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
A	1	IMU	16.00 Sphere	42.0	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	2	Rate Gyro	7 x 6 x 3	9.0	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	3	Star Tracker	5 dia x 12	12.5	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	4	Sun Sensor	6.9 x 6.5 x 3	4.66	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	5	Cont. Electronics	12 x 12 x 18	50	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	6	ACCE Lerometer	TBS*	TBS	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	7	Laser Radar	TBS*	35.0	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	8	Laser Radar Elect.	TBS*	TBS	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	9	Computer	5.4 x 10.5 x 19.8	65.0	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	10	Aux. Memory	9.6 x 8.1 x 5.8	20.0	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	11	Comp. I/F Unit	9.9 x 5.0 x 13.9	5.0	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	12	Data I/F Unit	9.9 x 9.9 x 13.9	5.0	Intertank/ Fwd Skirt	Adequate	Adequate	Notes 1, 4 and 5

Table 3-1 (cont)

Table 3-1 (cont)

LEGEND:
S=STRUCTURES
P=PROPULSION
T=THERMAL CONT.
A=AVIONICS

SYSTEM	ITEM	PHYSICAL DATA / LRU HARDWARE DESCRIPTION	DIMENSION (INCHES)	WEIGHT (POUNDS)	TUG LOCATION	TUG ACCESS	BASELINE GSE DEFINITION	REMARKS/NOTES
	13	Orbiter I/F Unit	TBS*	TBS*	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	14	Buffer/Formatter	9.9 x 5.0 x 13.9	10.0	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	15	Tape Recorder	9.6 x 7.9 x 5.8	12.5	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	16	Signal Conditioner	TBS*	TBS*	Fwd Skirt/ Intertank & Aft Skirt	Adequate	Adequate	Notes 1, 2, 4 and 5
	17	AESPA	TBS*	26.0	External/ Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	18	Cmd Decoder	TBS*	3.0	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	19	Cmd Distributor	TBS*	3.0	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	20	T.V. Camera	TBS*	7.0	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	21	T.V. Electronics	TBS*	7.0	Fwd Skirt	Adequate	Adequate	Notes 4 and 5
	22 ↓ 36	Measurement Sensors (15 types)	TBS*	TBS*	All	Adequate	Adequate	Notes 1 thru 5
	37	Fuel Cells	12 x 16 x 20	125/56	Intertank	Adequate	Adequate	Note 1
	38	Reactant Tank	TBS	50	Intertank	TBS	TBS	Note 1 (determination of access adequacy requires tank sizing requirements)

Table 3-1 (concl)

SYSTEM	ITEM	LRU HARDWARE DESCRIPTION / PHYSICAL DATA	DIMENSION (INCHES)	WEIGHT (POUNDS)	TUG LOCATION	TUG ACCESS	BASELINE GSE DEFINITION	LEGEND: S=STRUCTURES P=PROPULSION T=THERMAL CONT. A=AVIONICS REMARKS/NOTES
	39	Thermal Cont. Distr.	TBS*	12	Intertank	Adequate	Adequate	Note 1
	40	Battery	9 x 8 x 8	20	Intertank	Adequate	Adequate	Note 1
	41	Pwr. Proc. Unit	9 x 9 x 8	8.0	Intertank	Adequate	Adequate	Note 1
	42	Pwr. Distributor	12 x 15 x 8	12.0	Fwd Skirt/ Intertank	Adequate	Adequate	Notes 1, 4 and 5
	43	Cont. Distributor	10 x 10 x 6	10.0	Intertank	Adequate	Adequate	Note 1
	44	Main. Eng. Distr.	8 x 8 x 6	8 . 0	Intertank	Adequate	Adequate	Note 1
	45	APS Distributor	TBS*	*	Intertank	Adequate	Adequate	Note 1

NOTES:

1. Access through door in main skirt, located at ≈station 1128.0+ Z axis.
2. Access through back of aftskirt when aft adapter is removed, located at ≈station 1172.902, entire circumference.
3. Access through forward end of aft adapter when adapter is removed from Tug, located at ≈station 1172.902, entire circumference.
4. Access through doors in forward skirt, at ≈station 997.24 between +z and +Y axis.
5. Access through front end of fwd skirt with spacecraft not installed, at ≈station 935.99.

* Exact physical characteristics are unknown; however, general physical characteristics are sufficiently known to judge adequacy of access.

4.1.3 LO_2 Capacitive Mass Probe

The probability of a failure of the probe is rather remote, but is a distinct possibility, and such a failure would result in the need to remove the LO_2 tank to replace the probe. It is conceivable, however, that a hatch could be added in the aft end of the LO_2 tank that would allow for replacement of the capacitive mass probe as well as the level sensors.

4.1.4 APS Hydrazine Sphere

Current state-of-the-art materials and design techniques would indicate that the bladder contained in the hydrazine tanks may deteriorate before completion of 20 missions. Therefore, replacement and/or refurbishment of these tanks could be required. Access provisions identified for the intertank region in baseline documentation would not permit removal of this tank unless the Tug was separated at optional field splice Sta 1061.74. The recommended solution would be to increase the access door size, as indicated in para 4.1.2.

4.2 FUNCTIONAL AND SERVICE ACCESS PROVISIONS

This portion of the study was primarily directed toward the various functional blocks contained on the green light functional flow diagram developed under task 1.0. For purposes of this special emphasis study, it is convenient to combine the assessment of both functional and service access, as defined in para 1.0, because of their common origin in the flow diagram. Table 3-2 identifies each functional block and its required accessibility, and only those items having an apparent access problem are delineated in subsequent paragraphs.

Further, functional access primarily requiring an electrical or cabling interface is at this time considered adequate because of the lack of design definition in this area, and allowing confidence in competent designers to provide these provisions based on well-defined electrical and functional interface requirements.

Table 3-2 Functional/Service Access Evaluation

SYSTEM	FUNCTIONAL DESCRIPTION (OPERATIONAL FLOW)	NO ITEM	TYPE OF ACCESS FUNCT	SERVICE	TUG LOCATION	ACCESS	BASELINE GSE DEFINITION	LEGEND S=STRUCTURES P=PROPULSION T=THERMAL CONT. A=AVIONICS REMARKS/NOTES
	Del. T/A to KSC Shuttle Airfield	x						
	Unload T/A from Aircraft	x						
P	Verify and check tank breather and trans. instr.		x		Various	Adequate	Adequate	Visual Inspection/Data Analysis
	Move T/A to TPF	x						
	Perform receiving inspection		x		Various	Adequate	Adequate	Visual Inspection
	Install T/A in refurb. and cleaning fixture		x		Various	Adequate	Adequate	
	Install ship loose equipment		x		Fwd. skirt & intertank	Adequate	Adequate	Note 1
	Clean T/A		x		Entire T/A	Adequate	Adequate	
	Move T/A to TPF C/O Area	x						
	Install T/A in Maint. and C/O Fixture		x		Entire T/A	Adequate	Adequate	
	Shuttle Flt Ops	x						
	Orbiter Land at SHA	x						
	Orbiter Safe Verif. and Crew Exchange	x						
	Tow Orbiter to OPF	x						
	Unload Orbiter, Prop. F/C, Vent Press and Safe	x						

Table 3-2 (cont)

SYSTEM	FUNCTIONAL DESCRIPTION (OPERATIONAL FLOW)	NO ITEM	TYPE OF ACCESS FUNCT	SERVICE	TUG LOCATION	ACCESS	BASELINE GSE DEFINITION	LEGEND S=STRUCTURES P=PROPULSION T=THERMAL CONT. A=AVIONICS REMARKS/NOTES
	Install Orbiter GSE and Open P/L Bay Doors	x						
	Remove P/L and Install on Transporter		x		Entire T/A	Adequate	Adequate	
A	Remove Tape Recorder		x		Fwd Skirt	Adequate	Adequate	Note 1, Item A-15
	Remove S/C as required		x		Fwd Skirt	Adequate	Adequate	
	Remove COMMSEC Equip.		x		Fwd Skirt	Adequate	Adequate	
	Move T A to TPF airlock		x		Entire T/A	N/A	Adequate	
P	Safe and Remove Unexp. ordnance			x	TBS	TBS	TBS	Note 2
A	Service F/C and Reactant Tanks			x	Aft Skirt	Adequate	Adequate	Note 1, Items A-37 and A-38
P	Drain and Purge APS Lines and Tanks			x	Intertank	Adequate	Adequate	Note 1, Items P-43 thru P-49
P	Purge LO_2 Tank			x	Aft Skirt	Adequate	Adequate	
P	Purge LH_2 Tank			x	Aft Skirt	Adequate	Adequate	
A	Remove Battery		x		Intertank	Adequate	Adequate	Note 1, Item A-40
P	Vent Remaining Pressurants			x	Aft Skirt	Adequate	Adequate	
S	Separate Tug from Adapter		x		Aft Skirt	Adequate	Adequate	
	Visual Damage Insp. Tug		x		All	Adequate	Adequate	Note 3
	Clean and Prep. to Move Tug		x		All	Adequate	Adequate	

Table 3-2 (cont)

SYSTEM	FUNCTIONAL DESCRIPTION (OPERATIONAL FLOW)	NO ITEM	TYPE OF ACCESS FUNCT	SERVICE	TUG LOCATION	ACCESS	BASELINE GSE DEFINITION	LEGEND S=STRUCTURES P=PROPULSION T=THERMAL CONT. A=AVIONICS REMARKS/NOTES
	Move Tug to TPF, C/O Area		x		Entire Tug	Adequate	Adequate	
	Install Tug in Maint./checkout fixture		x		Entire Tug	Adequate	Adequate	
	Isolate failed hardware causing mission anomalies		x		Fwd skirt/ intertank and aft skirt	Adequate	Adequate	Note 1
	Update post-flt Maint. Activity Plan	x						
	Scheduled pre-Maint. Test		x		Fwd. Skirt/ Intertank and aft skirt	Adequate	Adequate	
	Complete Repl. Comp. Kit Build-up		x		Fwd. Skirt/ Intertank and aft skirt	Adequate	Adequate	Note 1
	Sched. Maint. & Modifications		x		Fwd Skirt/ Intertank and aft skirt	Adequate	Adequate	
	Unschd. Maint.		x		Fwd Skirt/ Intertank and aft skirt	Adequate	Adequate	Note 4
	Mission Config.		x		Fwd Skirt	Adequate	Adequate	This activity limited to software and COMMSEC equipment
	Install Adapt. in Maint. and C/O Fixture	x						
	Isolate failed hardware causing anomaly		x		Aft adapter	Adequate	Adequate	Note 1

Table 3-2 (cont)

SYSTEM	FUNCTIONAL DESCRIPTION (OPERATIONAL FLOW)	NO ITEM	TYPE OF ACCESS FUNCT	SERVICE	TUG LOCATION	ACCESS	BASELINE GSE DEFINITION	LEGEND S=STRUCTURES P=PROPULSION T=THERMAL CONT. A=AVIONICS REMARKS/NOTES
	Sched. Maint. & Mods.		x		Aft Adapter	Adequate	Adequate	
	Unsched. Maint.		x		Aft Adapter	Adequate	Adequate	Note 4
	System Verification		x		Aft Adapter	Adequate	Adequate	Deployment C/O
	Prep for mate with Tug	x						
	Mate Tug/Adapter Verify Mech. and Elect. Interfaces		x		Aft Skirt and Adapter	Adequate	Adequate	
A	Electrical pre-power checks		x		Fwd Skirt Intertank	Adequate	Adequate	
A	Critical alignment verification		x		Fwd Skirt	Adequate	Adequate	
A	Apply Pwr to T/A		x		Fwd skirt intertank and aft skirt	Adequate	Adequate	
A	Load PCM Data Format		x		Fwd Skirt and Aft Skirt	Adequate	Adequate	
A	Measurement system E to E calibration		x		All	Adequate	Adequate	Step Cal. signals in lieu of sensor stimulation
A	Replaced LRU's verification		x		All	Adequate	Adequate	
T	Service Active T/C System			x	Intertank	Adequate	Adequate	Freon Service Available in Intertank Region
	Verify S/C Interface and prep. for IST		x		Fwd Skirt	Adequate	Adequate	Visual Inspection, elect. & mech. connections

Table 3-2 (cont)

SYSTEM	FUNCTIONAL DESCRIPTION (OPERATIONAL FLOW)	NO ITEM	TYPE OF ACCESS: FUNCT	TYPE OF ACCESS: SERVICE	TUG LOCATION	ACCESS	BASELINE GSE DEFINITION	LEGEND S=STRUCTURES P=PROPULSION T=THERMAL CONT. A=AVIONICS / REMARKS/NOTES
A	Load and verify computer soft-ware		x		Fwd Skirt/ Aft Skirt	Adequate	Adequate	Computer Simulation
All	Systems Health Check		x		All	Adequate	Adequate	LPS Checkout
P	Install ordnance and safe			x	TBS	TBS	TBS	Note 4
S	Mate T/A and Spacecraft		x		Fwd Skirt	Adequate	Adequate	
	Connect S/C GSE or connect S/C Sim.	x						
	T/S - S/C inter-face verification		x		Fwd Skirt	Adequate	Adequate	Visual inspect-ion elect. & mech. connections
A	Load and Verify Comp. Flight Software		x		Fwd Skirt and Aft Skirt	Adequate	Adequate	Computer Simulation
All	Functional I/F Test		x		All	Adequate	Adequate	LPS Checkout
	S/C to STDN/ TDRSS/SCF comm-unication verify	x						Non-Secure Spacecraft
A	P/L to orbiter communication verify		x		Fwd Skirt	Adequate	Adequate	TPF - has adequate external antenna system
P	Connect and verify ordnance safe			x	TBS	TBS	TBS	Note 4
A	Install flight battery			x	Intertank	Adequate	Adequate	Note 1, Item A-40
	Move to APS propellant load-ing area	x						

Table 3-2 (cont)

SYSTEM	FUNCTIONAL DESCRIPTION (OPERATIONAL FLOW)	NO ITEM	TYPE OF ACCESS FUNCT	SERVICE	TUG LOCATION	ACCESS	BASELINE GSE DEFINITION	LEGEND S=STRUCTURES P=PROPULSION T=THERMAL CONT. A=AVIONICS REMARKS/NOTES
P	Load APS, Leak Check and Secure			x	Intertank	Adequate	Adequate	
P	Partial Tug Press Load			x	Intertank	Adequate	Adequate	APS - H_e tank to 3000 psia
	Prep to move and install in P/L cannister	x						
	Verify cannister enviro. and move to pad.			x	All	Adequate	Adequate	
	Install cannister on PCR and mate P/L to facility		x		All	Adequate	Adequate	
	Remove GSE, prot. covers and prep. for Orbiter mate	x						
	Extend PCR, open P/L bay doors	x						
S	Mate P/L with Orbiter		x		Aft Adapter	Adequate	Adequate	Mech. Mate and Umbilical Connect.
	P/L - Orbiter Interface Verification		x		Aft Adapter and main shell	Marginal	Adequate	See para 4.2.2.1
A	Payload Measurement Profile		x		All	Adequate	Adequate	LPS/Orbiter Step Cal. for Orbiter Record. Verification
All	Orbiter - P/L functional interface verify		x		All	Adequate	Adequate	LPS Checkout
	Final S/C servicing and flight prep. (N/F)	x						
	Cabin closeout	x						

Table 3-2 (cont)

SYSTEM	FUNCTIONAL DESCRIPTION (OPERATIONAL FLOW)	NO ITEM	TYPE OF ACCESS FUNCT	SERVICE	TUG LOCATION	ACCESS	BASELINE GSE DEFINITION	LEGEND S=STRUCTURES P=PROPULSION T=THERMAL CONT. A=AVIONICS REMARKS/NOTES
	Close Orbiter P/L Bay Doors	x						
	S/C in Standby Status	x						
	Retract PCR and Pad Closeout	x						
P	Load Pressurants			x	Aft Adapter Service Panel	Adequate	Adequate	
All	Countdown	x						
P	Load LH_2			x	Aft Adapter & Service Panel	Adequate	Adequate	
P	Load LO_2			x	Aft Adapter & Service Panel	Adequate	Adequate	
P	Load F/C Reactants			x	Aft Adapter and Service Panel	Inadequate	Adequate	See para. 4.2.3.1
	Terminal Count-down and launch			x	All	Inadequate	Adequate	See para. 4.2.3.1
	Record flight performance data (real time)	x						
	Analyze flt perf. data	x						
	Prep. post-flt maint. activity plan	x						
	Draw spares and mod. comp. for replace.	x						

Table 3-2 (cont)

SYSTEM	FUNCTIONAL DESCRIPTION (OPERATIONAL FLOW)	NO ITEM	TYPE OF ACCESS FUNCT	TYPE OF ACCESS SERVICE	TUG LOCATION	ACCESS	BASELINE GSE DEFINITION	LEGEND S=STRUCTURES P=PROPULSION T=THERMAL CONT. A=AVIONICS REMARKS/NOTES
All	Flight Abort	x						
	Orbiter Land at SHA	x						
	Safe Orb, Systems and connect gnd. cooling	x						
P	Connect LH_2 gnd vent and dump lines			x	Aft Adapter and Service Panel	Adequate	Adequate	
P	Boil-off and burn LH_2	x						
P	Purge LO_2 tank and lines			x	Aft Adapter and Service Panel	Adequate	Adequate	
P	Purge LH_2 Tank and Lines			x	Aft Adapter and Service Panel	Adequate	Adequate	
All	Verify systems safe and prep to move		x		All	Adequate	Adequate	Limited to LH_2 and LO_2 Drain and Purge
	Move Orbiter to OPF	x						
	Unload Orbiter Prop., vent press. and safe systems	x						
	Install GSE, open P/L bay doors	x						
S	Remove Payload & Install on Transporter		x		Entire T/A	Adequate	Adequate	
S	Separate S/C from T/A		x		Fwd Skirt	Adequate	Adequate	

Table 3-2 (concl)

SYSTEM	FUNCTIONAL DESCRIPTION (OPERATIONAL FLOW)	NO ITEM	TYPE OF ACCESS FUNCT	SERVICE	TUG LOCATION	ACCESS	BASELINE GSE DEFINITION	LEGEND S=STRUCTURES P=PROPULSION T=THERMAL CONT. A=AVIONICS REMARKS/NOTES
A	Remove COMMSEC Equipment		x		Fwd Skirt	Adequate	Adequate	
	Processing flow evaluation		x					

NOTES:

1. Evaluated as LRU's, Ref. Table 2.1.5-1 for LRU accessibility.
2. Need further ordnance and safety data to determine adequacy of access.
3. Primarily structural visual inspection, identify LRU replacement requirements.
4. Ref. Table 2.1.5-1 for candidateLRU's.

4.2.2 Functional Access Problems

During payload-to-Orbiter interface verification of mechanical and electrical connections, there exists the necessity to perform visual inspection of umbilical and payload mounting points in the Orbiter bay. Current baseline design in conjunction with payload accommodations documentation would indicate that payload mounting points, in general, are accessible with the exception of that point located at Sta 1128 in the minus z axis. In order to perform this verification, one of two possible solutions become apparent. The first would be to provide some form of TV monitoring in the Orbiter payload bay that would allow complete visual access along the underside of the payload, or provide switch monitoring of all physical connection points with connect/disconnect status displayed in the Orbiter cabin. This latter solution is preferred as the most economical and the least weight penalty fix to provide adequate access. This problem also exists with regard to visual inspection of umbilical connections; the indicated solutions could also correct this problem.

4.2.3 Service Access Problems

During propellant load phase of the countdown, a requirement exists to load fuel cell reactants. The baseline configuration document implies that these will be LH_2 and LO_2. The Shuttle payload accommodations documentation indicates provision for GH_2 and GO_2 for accumulator filling. This would result in the need for addition of liquid provision on both the fuel and oxidizer servicing panels to accommodate fill, drain of reactant tanks, as well as topping activities during terminal countdown.

Addendum 4 Payload Changeout

MCR-74-488
NAS8-31011

Addendum 4 January 1975

REVERIFICATION AND CHECKOUT
OF TUG-TO-ORBITER INTERFACES
IN EVENT OF TUG AND/OR PAYLOAD
CHANGEOUT AT THE PAD

Prepared by

Q. Eberhardt
Systems Engineer

CONTENTS

1.0 INTRODUCTION

Payload changeout has been investigated to determine the functional, timeline, and resource requirements for changing out various payload alternatives after the payload has been installed in the Orbiter bay. The payload changeout alternatives include changeout (1) spacecraft only, (2) Tug only, (3) both spacecraft and Tug, and (4) spacecraft only with Tug remaining in the Orbiter bay. The time for changeout considered were (1) before fuel cell reactant loading (T-10 hr), before cryogenic loading of main propellants (T-2 hr), and after cryogenic loading of main propellants (T-1 hr). These three times generally cover the range of significant impacts and requirements to the Shuttle, payload, and the facility.

Payload changeout can be initiated as a result of two conditions: (1) a failure in some payload element, and (2) a priority payload requirement (e.g., a payload of opportunity). A failed payload element could cause either a Spacecraft or a Tug to be changed out, whereas a priority payload could cause either a spacecraft or an entire payload to be changed out. The exact combination changed out will depend not only on these conditions but will also depend on the traffic or mission model and the status of other Tugs and spacecraft at the time changeout is initiated. For this reason, all possible changeout combinations have been included.

Summary and Conclusions - Table 4-1 summarizes the impact of changing out the various alternatives on the resources and timelines.

Shuttle timelines are affected by all payload changeouts, otherwise the impact on the Shuttle is zero if changeout is initiated before reactant loading for fuel cells (T-10 hr). If fuel cell reactants have been loaded, they must be unloaded and purged. If changeout occurs after external tank loading, the external tanks must be unloaded and purged. The Shuttle must be "safed" for personnel access. This includes: reducing storage vessel pressures to levels consistent with manned access, safing all ordnance circuits, and deactivating all ordnance and energy system busses, e.g., OMS, RCS, etc. Regardless of when changeout occurs (T-10, T-2 or T-1) the Orbiter bay doors must be cycled open/closed 2 to 4 times depending on what is changed out; and additionally, the Orbiter power must be removed from the Tug.

Table 4-1 Impact of Changeout on Resources and Timelines

Item Changed Out \ Impact	Impact Shown as Delta to "Green Light" Requirements					Remarks
	GSE	Facility	Manpower, hr	Software	Timelines (Additional hr to Launch)	
Spacecraft Only	No Impact	Spacecraft Stowage in PCR (Two) Spacecraft Access in Orbiter Bay PCR Crane Translation Payload Manipulator Mate/Fit of Tug and Spacecraft	310 (T-1) 304 (T-2) 264 (T-10)	LPS Program for Unloading and Safing	37 (T-1) 33½ (T-2) 19½ (T-10)	Priority Spacecraft Changeout or Spacecraft No-Go
Spacecraft and Tug		No Impact	256 (T-1) 230 (T-2) 210 (T-10)		33½ (T-1) 30 (T-2) 22 (T-10)	Priority Changeout or Spacecraft No-Go
Tug Only		Spacecraft Stowage in PCR (Two) Spacecraft Access in Orbiter Bay PCR Crane Translation Payload Manipulator Mate/Fit of Tug and Spacecraft	342 (T-1) 325 (T-2) 296 (T-10)		42 (T-1) 38½ (T-2) 30½ (T-10)	Tug No-Go
Spacecraft Only - Tug Remains in Orbiter Bay			243 (T-1) 226 (T-2) 197 (T-10)		31½ (T-1) 28 (T-2) 20 (T-10)	Priority Spacecraft Changeout or Spacecraft No-Go

It is the conclusion of the study that:

1) Changeout of the total payload should be considered the standard approach if spacecraft-to-Tug integration can be done "off-line" and in "parallel time."

2) For priority payload changeout, total payload changeout should be considered standard unless the option to keep the Tug in the Orbiter bay is retained.

3) For changeout of certain spacecraft (regardless of reason), the option of retaining the Tug in the Orbiter is attractive and should be considered.

4) If another Shuttle/Tug is within 28 to 42 hours of launch readiness, payload changeout may not always be the best alternative for priority payload missions.

2.0 GUIDELINES, GROUND RULES, AND ASSUMPTIONS

Any spacecraft and/or Tug which is brought to the PCR for changout will be ready for Tug and spacecraft integration.

The capability to routinely mate and integrate the Tug and spacecraft in the PCR exists independently of the changeout requirement.

The ability of the Shuttle facility to unload cryogenics and pressurants from the Shuttle and the Tug exists independently of the changeout requirement (a contingency capability).

The baseline function No. 6.7 and 6.9 of the operational baseline define the Tug/Orbiter interface testing which is required as an operational routine. These same interface tests must be performed again on all payload changeouts where the Tug has been physically separated from the Orbiter.

3.0 SUMMARY OF RESULTS

As Table 4-1 depicts, for a priority Spacecraft changeout or spacecraft No-Go, the best approach is to changeout either the entire payload or changeout the spacecraft only, but leave the Tug in the Orbiter bay. Either of these options will save approximately 50 man-hours of effort and from one half to a full shift of time. Replacing the entire payload is contingent upon the capability to mate and integrate the spacecraft and Tug "off-line" and in "parallel time." If that contingency is not true for an individual case, then removing the spacecraft but leaving the Tug in the Orbiter bay is the attractive option. NASA TM X-64751, Revision 2, the October 1973 Space Shuttle Traffic Model, dated January 1974, lists several spacecraft and Spacecraft combinations of lengths and diameters and allow 360-deg access around the spacecraft in the Orbiter bay, and clearance to lift the spacecraft from the Tug (diameters from 2, 5, 6, 7, 8, and 10 ft, and lengths from 5 to 25 ft).

Changing out the Tug-only would occur only for a Tug No-Go and that option would have to be traded off against the time required and ability to fix the No-Go in place or in the PCR. Any repair or replacement which takes less than 42 hours, to get back to launch would be an attractive alternative to Tug changeout.

There is no impact to the GSE for any of the payload changeout options. This is primarily caused by the fact that PCR mate and integration of spacecraft and Tug is one of the "green light" options; and since that capability exists, it would be used for changeout as well. Also, in general there are no GSE requirements after the payload is moved to the pad (only facility and software requirements).

The impact to the facility is minimal. The only additional requirements that payload changeout imposes is on the PCR and the payload manipulator. The PCR (Fig. 4-1) must be able to temporarily stow two spacecraft (the new one and the one being changed out); and to do this, the PCR crane must have translation capability. The payload manipulator must provide access to and around the spacecraft in the Orbiter bay and must accommodate a spacecraft-to-Tug mate and functional interface test (FIT) either in the PCR or Orbiter bay (Fig. 4-2 and 4-3). Of course, the LPS will be required to perform the FIT, but that requirement is not unique to changeout so is not listed as an additional requirement. Also, it is noted that changeout of the entire payload imposes no requirements on the facility above and beyond green light requirements.

The additional man-hours, and the additional hours required to launch the vehicle as depicted in Table 4-1 for the three conditions were determined as shown in Figure 4-4.

The LPS programming for propellant/pressurant unloading and safing is listed as additional requirements to the green light even though it is not unique to changeout. These programs will always be required for every launch for contingencies that may arise during a countdown.

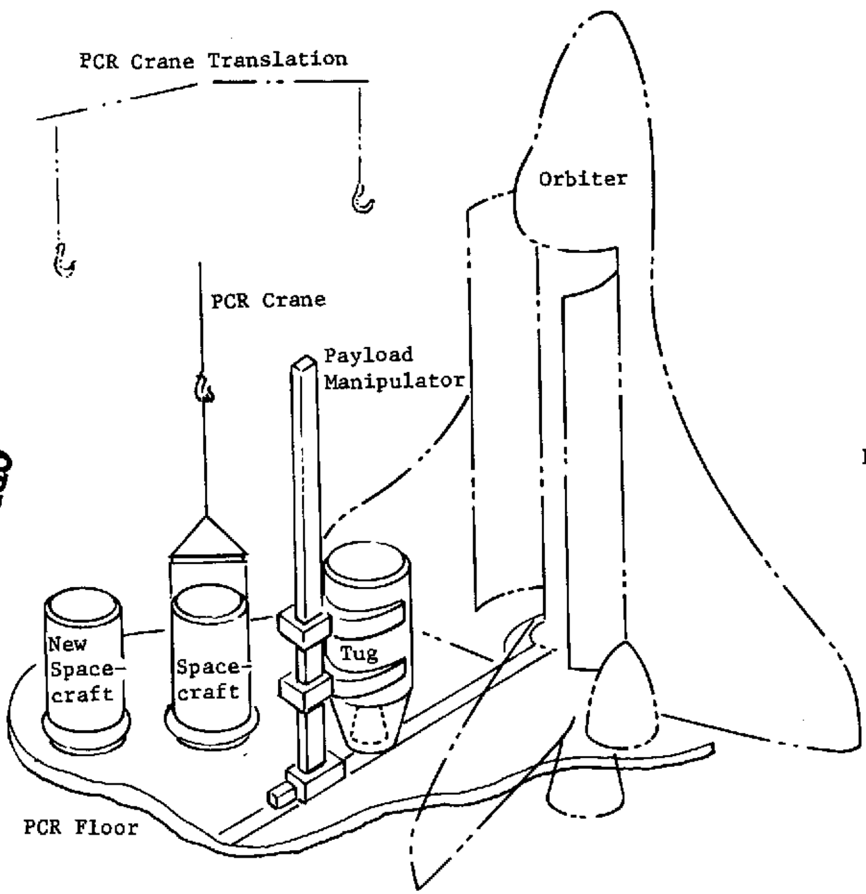


Figure 4-1
PCR Crane and Spacecraft Stowage Requirements, Spacecraft or Tug Changeout

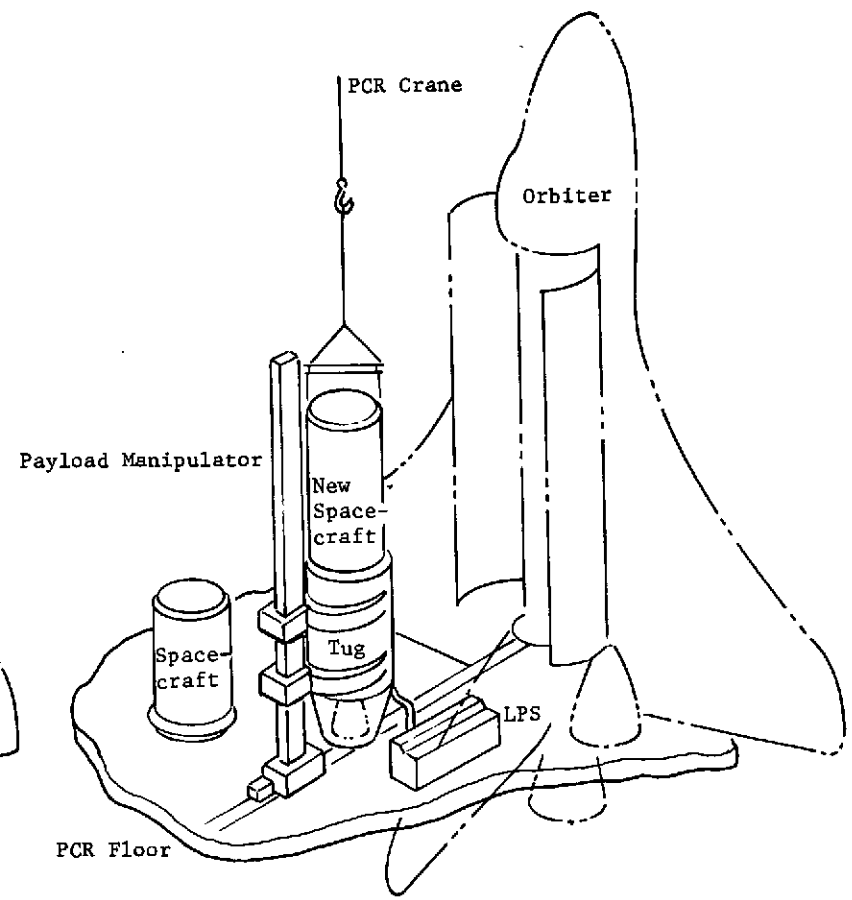


Figure 4-2
Payload Manipulator Spacecraft and Tug Mating and FIT Requirements in the PCR

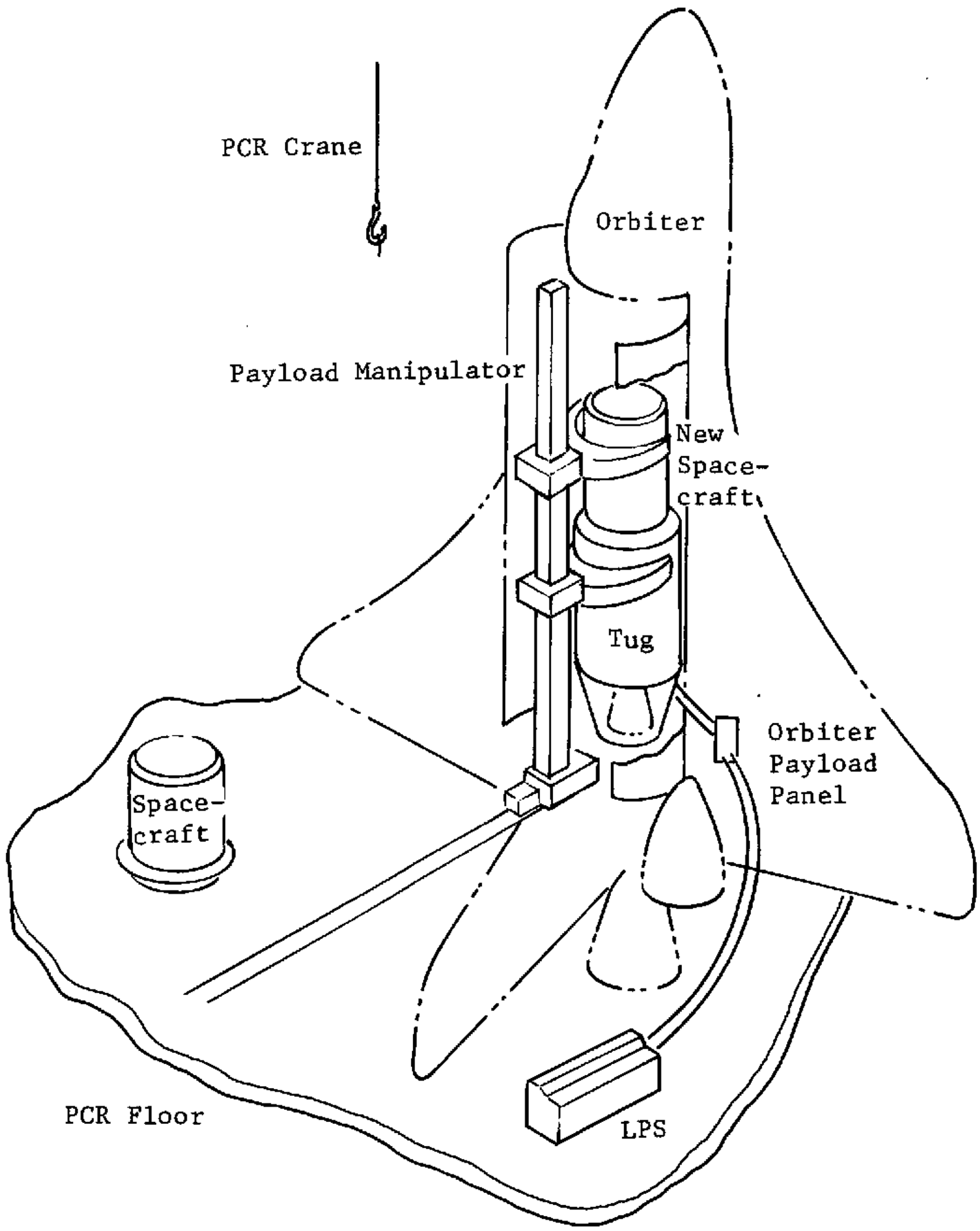
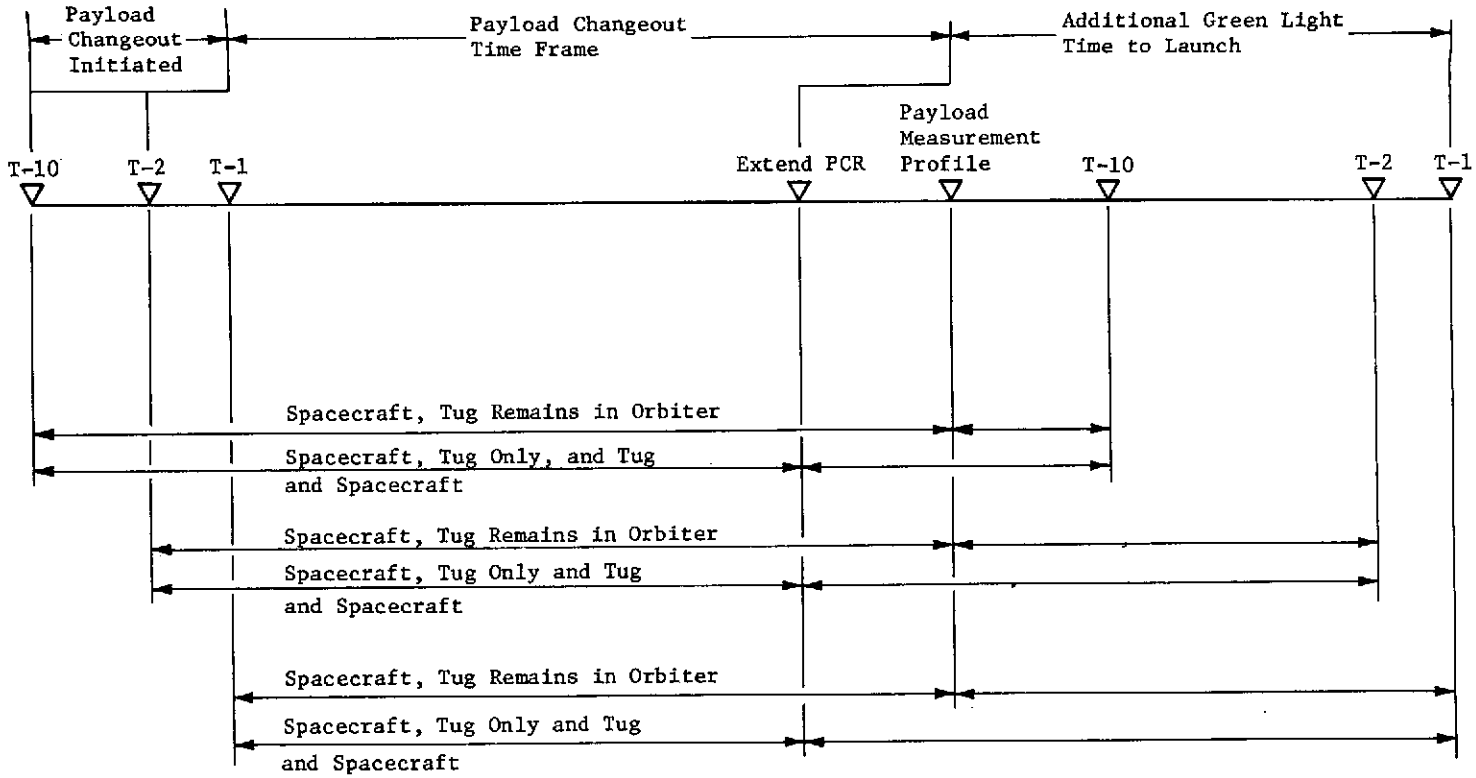


Figure 4-3
Payload Manipulator Spacecraft and Tug Mating and FIT Requirement in the Orbiter Bay



From Figures 6, 7, 8, 9 — From "Green Light" Stick and Ball Chart

Additional Man-Hours to Launch = $\sum$ Man-Hours for Payload Changeout and Additional Green Light

Additional Time to Launch = $\sum$ Payload Changeout Time and Additional Green Light Time

From Figures 6, 7, 8, 9 — From Greenlight Stick and Ball Chart

Figure 4-4
Method for Determining Additional Man-Hours and Hours for Payload Changeout Options

4.0 DISCUSSION

Each of the functions involved in each payload option has been analyzed to determine the resource and timeline requirements. These functions are depicted in Figure 4-5; the resource and timeline requirements, as well as the functions, are depicted in Figures 4-6 through 4-9. Collectively, these figures make up the basic analysis that led to the summary and conclusions.

It is noted that the assumption has been made that all Orbiter/Tug interfaces must be reverified after disconnection. Some discussion of that assumption is warranted. The Tug/Orbiter interface includes propellant lines, pressurant lines, and multi-pin electrical connectors. These are each broken in all changeout options except when the Tug remains in the Orbiter. Whenever these lines are broken, the fluid lines must be reverified to leak criteria; and continuity checks must be made on the pin connections. As there is either a new Tug, new spacecraft, or both, the power on tests must be redone on the new configuration. These tests should be the same on the new configuration as on the original configuration in order to have the same confidence at launch.

Addendum 5 Propellant Loading

MCR-74-488
NAS8-31011

Addendum 5 January 1975

PROPELLANT LOADING SPECIAL
ASSESSMENT STUDY

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CONTENTS

Figure

1.0 INTRODUCTION

This special emphasis assessment considers the requirements associated with Tug propellant loading so as to identify any impact on the Orbiter before Orbiter PDR. Several secondary goals to be accomplished by this study are:

1) Determine optimum location for loading APS propellants and pressurants.

2) Provide synopsis of all propellant loading activities during ground turnaround cycle.

3) Determine loading functions and identify design assumptions/modifications for the Tug APS propellant loading, Tug APS/MPS pressurant loading, Tug fuel cell reactant servicing, Tug MLI purge, Tug MPS propellant loading, and fluid servicing panels.

This special emphasis assessment relies extensively on the results of previous Tug ground operations where applicable.

2.0 GROUND RULES AND ASSUMPTIONS

1) Cryogenic propellant loading of the Orbiter External Tank and Tug should be accomplished within the time span allowed for External Tank loading.

2) Both LH_2 and LO_2 may be loaded simultaneously.

3) Tug cryogenic propellant loading shall be accomplished remotely with the Tug in the Orbiter payload bay with the payload bay doors closed.

4) Helium for the LH_2 and LO_2 purge bags is supplied by the ground and MPS pressurization systems.

5) MLI purge system is assumed.

6) MPS propellants can be vented through the thermodynamic vent into the nonpropulsive vent for each system (Fig. 3.3-6, Vent Relief System, Baseline Space Tug Configuration Definition, MSFC 68 M00039-2).

3.0 SUMMARY OF RESULTS

Events relating to propellant activities were extracted from the Tug ground operations functional flow diagram to provide a summary reference. This propellant operations flow summary is shown in Figure 5-1 in para 4.1.

Additional umbilicals were identified for the Orbiter LH_2 and LO_2 T-0 launch umbilical panels. They were (1) fuel cell supply, (2) fuel cell vent, and (3) MLI purge vent.

Ground propellant activities on the Tug are predicted on Tug conditions when it returns from a normal mission. This assumes the main propellants have been vented to approximately 2 psia in space, and the tanks repressurized with helium, any remaining quantities of APS propellant and pressurant is locked up, the Tug/Orbiter fluid umbilicals are reconnected, and the fuel cell reactants are vented. The propellant and pressurant potential hazards in the form of chemical energy (residual hydrogen vapors and residual hydrazine) and pressure energy (MPS and APS) are known and are safety manageable in Tug postlanding conditions.

The Tug APS system will be loaded with N_2H_4 in the TPF after mating with the spacecraft and subsequent checkout. The Tug APS and MPS helium will be loaded to 1100 psig concurrently with the Tug APS propellant loading. Preloading in the TPF minimizes operations at the pad during the critical final 10 hours before launch. Four modifications were recommended to the baseline Tug APS as shown in Figure 5-2 in para 4.2.

The final Tug APS/MPS pressurant loading is accomplished with the Tug and spacecraft in the Orbiter bay starting at T-10 hours. A recommended modification to the Tug APS helium system is to increase the final pressure from 3000 psia to 3200 psia so that both the APS and MPS helium systems can be loaded concurrently from the same ground systems.

The Tug fuel cell will be serviced on-pad starting at T-10 hours concurrently with servicing of the Orbiter fuel cells. The proposed Orbiter fuel cell loading system was expanded to provide Tug fuel cell servicing capability. It is recommended that the Tug fuel cell reactant tanks are vacuum jacketed dewars with density and temperature sensor probes.

The Tug MLI helium purge starts immediately after installation of the Tug in the Orbiter bay, assuming the purge bag containing a dry helium atmosphere is previously sealed. A design modification in the form of a proposed MLI system configuration is recommended.

The Tug MPS cryogenics will be loaded concurrently with Shuttle ET cryogenic loading within 75 minutes starting at T-2 hours. Loading events were staggered so that flows will be started, changed, or stopped in only one system at one time. Separate Tug and Shuttle cryogenic propellant loading systems are recommended so as to eliminate pressure surges on the Tug from the Shuttle loading system, to better control Tug propellant flow, and to minimize Orbiter onboard weight.

Safety aspects of Tug propellant loading and servicing activities were considered. The Auxiliary Propulsion System (APS) propellant hydrazine (N_2H_4), is stable in a contained system and allows the APS to be loaded early in launch preparation. Two-step loading of helium assures thermal stabilization and minimizes stresses on the airborne tank during final loading. Loading events for the cryogenic fuel cell and MPS loading were sequenced to avoid simultaneous events occurring in different systems; either LH_2 and LO_2, or Orbiter and Tug. Hazards in the Tug propellant loading operations are known and are safety manageable.

4.0 DISCUSSION

4.1 TUG PROPELLANT OPERATIONS FLOW

The functions of Tug propellant loading have been extracted from the overall Tug functional flow to provide visibility and continuity to propellant loading activities. The propellant loading operations plan summary is shown in Figure 5-1 for a green light, single cycle operation.

The ground operations on the Tug are predicted on the condition of the Tug when it returns from a normal mission. A Special Emphasis Assessment study on Tug safing requirements at post-landing established the following philosophy.

1) <u>Before Retrieval of Tug by Orbiter</u> - Vent main propellants down to approximately 2 psia. Venting hydrogen down to approximately 1 psia in space ambient conditions may create conditions where hydrogen can exist simultaneously as a solid, liquid, or gas. (Triple point.)

2) <u>After Retrieval of Tug by Orbiter but before Re-entry</u> - Secure the APS (lock up any remaining quantities of APS propellant and pressurant). Verify Tug/Orbiter fluid umbilicals are reconnected. Vent fuel cell reactants.

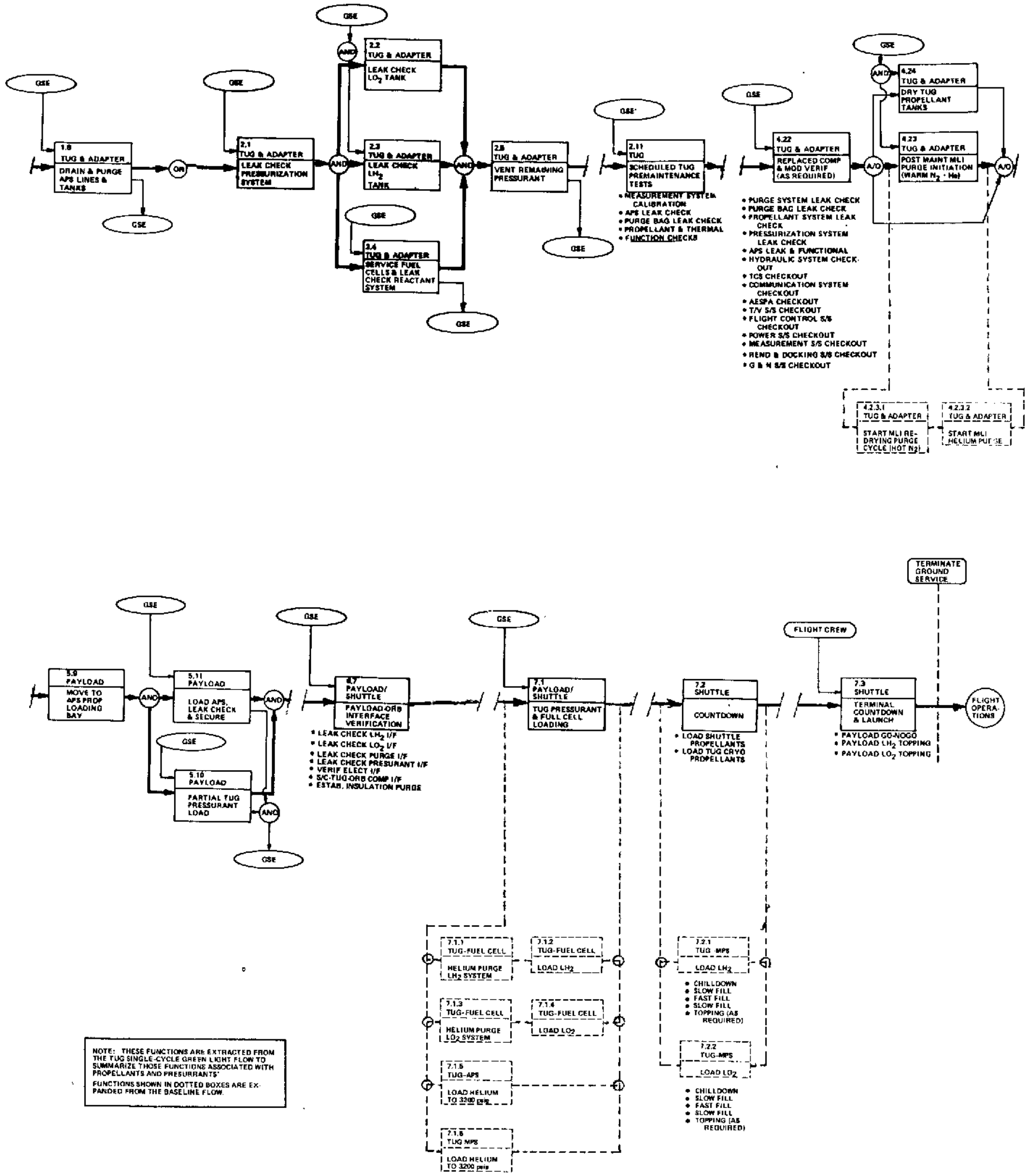


Figure 5-1 Propellant Operations Flow Summary

3) Tug Postlanding Propellant and Pressurant Potential Hazard Status - The returning Tug contains chemical energy in the form of residual hydrogen vapor in the propellant tank and fuel cell reactant tank, and residual hydrazine in the APS tank and lines. The returning Tug also contains pressure energy in the main propellant tanks, fuel cell reactant tanks, pressurization systems, and in the APS tank.

.2 TUG APS PROPELLANT LOADING

4.2.1 Function Description

The Tug APS system will be loaded with hydrazine in the Tug Processing Facility (TPF) after checkout and before installation in the Orbiter. The APS and MPS helium will be loaded to 1100 psig concurrently with APS propellant loading. The 1100 psig pressure maintains a safety factor of ≥ 4.0 on the pressurant system for subsequent handling.

Several alternative locations were considered for loading N_2H_4. These included loading in the Orbiter bay with the payload bay doors closed, loading in the Orbiter bay with the payload bay doors open, loading in the PCR, and loading in the TPF. Loading N_2H_4 with the Tug in the payload bay or in the PCR offers the advantage of operations flexibility in the case of payload changeout with the disadvantage of operations complexity in the final countdown.

The alternative of loading the N_2H_4 in the TPF was selected since the loading could be done there without impacting the Orbiter timeline and with maximum safety. Preloading of hydrazine in the TPF minimizes the operations at the pad during the critical final 10 hours before launch. This reduces operations complexity and improves probability of launch success. Should a problem develop in the TPF, the APS could still be loaded at the pad since the APS servicing unit could be a mobile cart. The Tug APS loading schematic and facility requirements are shown in Figure 5-2. Loading the APS requires approximately 1½ hours as shown in Figure 5-3.

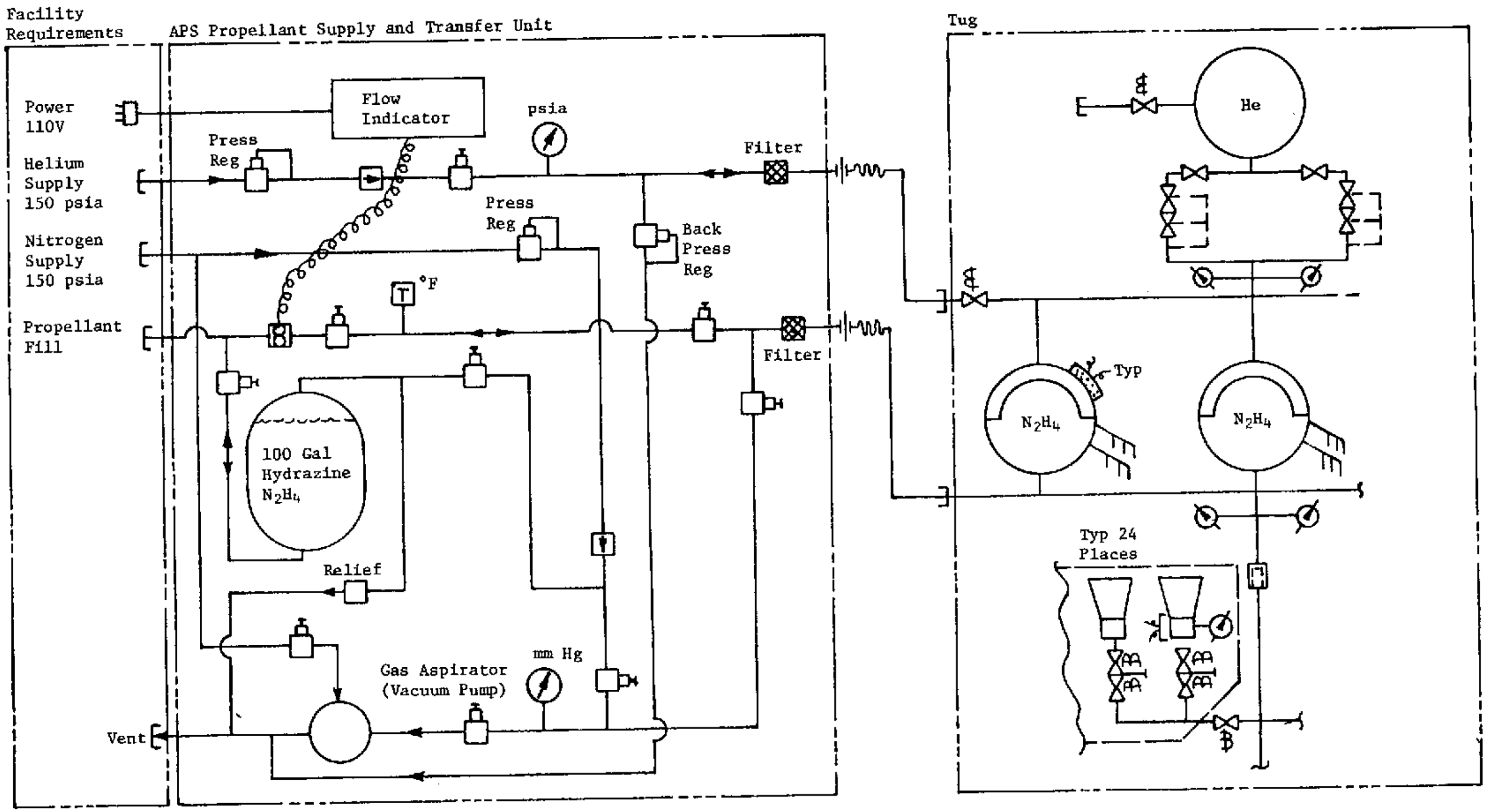
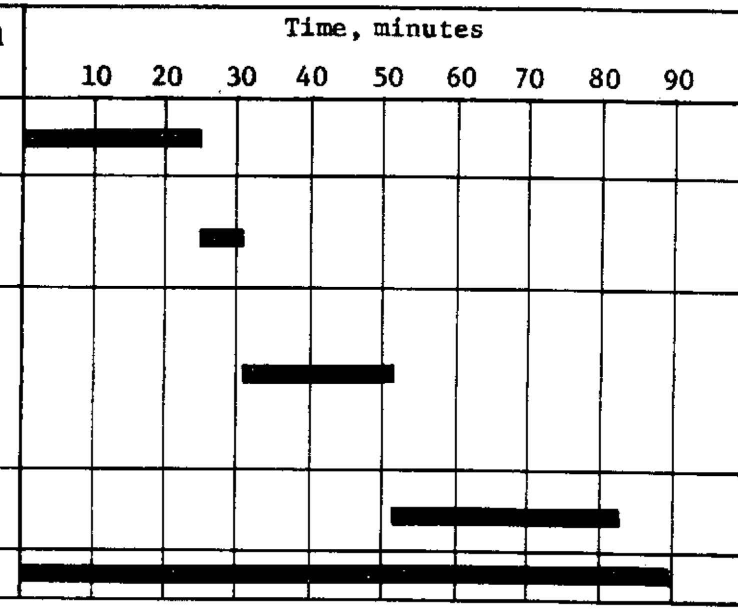


Figure 5-2 Tug APS Loading Schematic

Operational Sequence	Elapsed Time
1. Connect APS servicing unit to airborne system and bleed-in hydrazine.	25
2. Pull vacuum on airborne propellant tank outlet with nitrogen gas aspirator (25 to 30 mm Hg)	
3. Load hydrazine at 3 gpm. $\frac{500\text{ lb hydrazine }(7.5\text{ gal/ft}^3)}{62.9\text{ lb/ft}^3\ 70^\circ\text{F}} = 59.6\text{ gal}$ $\frac{59.6\text{ gal}}{3\text{ gpm}} = 19.9\text{ min}$	5
4. Disconnect APS servicing unit from airborne system and verify no leakage	20
5. Total Time Allocated	



Assumptions: The APS servicing unit has been leak checked, flow meter calibration verified, and loaded with approximately 100 gal hydrazine before Tug APS loading.

This operation could be performed several days before Tug APS loading.

Figure 5-3 Tug APS Propellant Loading Timeline

Figure 5-3

4.2.2 Recommended Modification

Several modifications are recommended to accommodate checkout and servicing of the APS. These modifications are shown in Figure 5-4.

1) A servicing port is recommended between the series valves ahead of each thruster to provide for functional and leak check of each valve. This capability also provides an effective way to purge the system and decontaminate as required without contaminating the catalyst bed of the thruster.

2) Solenoid valves, plus a quick disconnect and cap, are recommended for pressurant servicing of the He sphere and the N_2H_4 bladder tanks (two places) to provide series isolation at the servicing connections. The pressure regulator in the ground servicing fill connection should be deleted.

3) Isolation valves are recommended between the helium storage tank and the pressure regulators to accommodate concurrent hydrazine and helium loading. During loading of the APS propellant tanks, helium must first be applied to bottom the bladder in the tank, then vented as the liquid displaces the helium gas during fill. The isolation valves allow loading of hydrazine and helium concurrently and the flight pressurization of the propellant tanks to be delayed until the final count, or later.

4.3 TUG APS/MPS PRESSURANT LOADING

4.3.1 Function Description

The helium storage tank is prepressurized to 1100 psig to minimize heating effect during final pressurization at the pad caused by the heat of compression. The prepressurization will assure thermal stabilization at the pad; thereby maximizing helium loaded and minimizing stresses on the airborne storage tank caused by pressure and temperature. An estimated thermal stabilization rate is shown in Figure 5-5 for the two-step loading, based on previous analysis and test of a similar system. An estimated thermal stabilization rate for the helium storage tank loaded in a single step function on the pad is also shown. Such a loading would exceed the 4-hour time span allocated by the Shuttle for Tug APS and pressurant servicing, but could be accomplished within the 10 hours preceding launch.

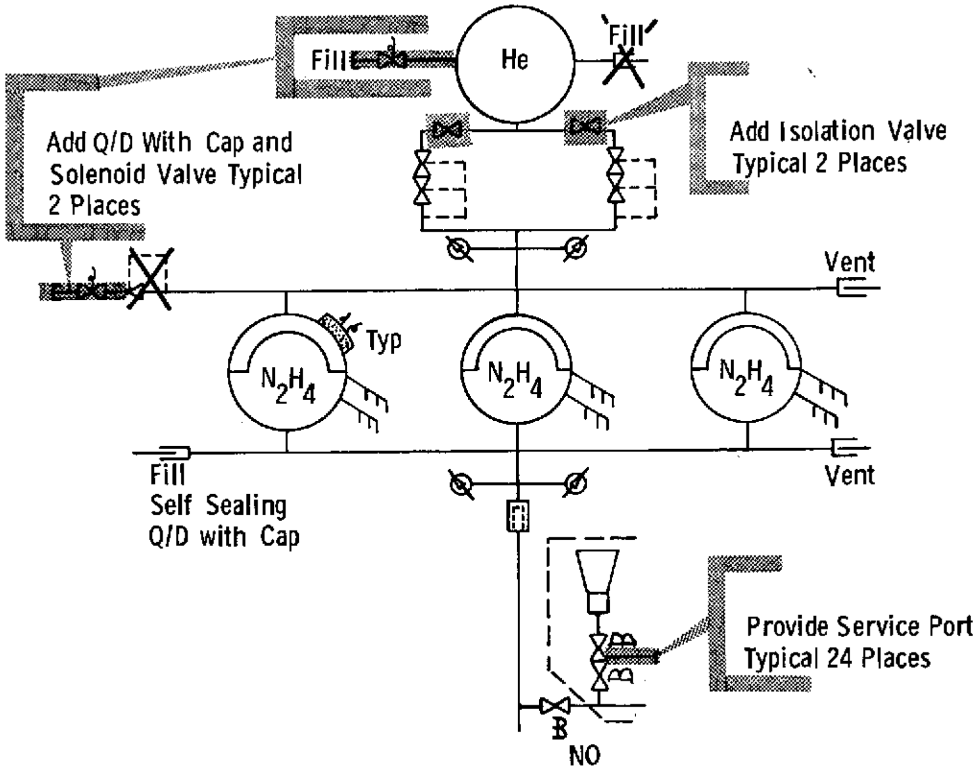


Figure 5-4 Tug APS Recommended Modifications

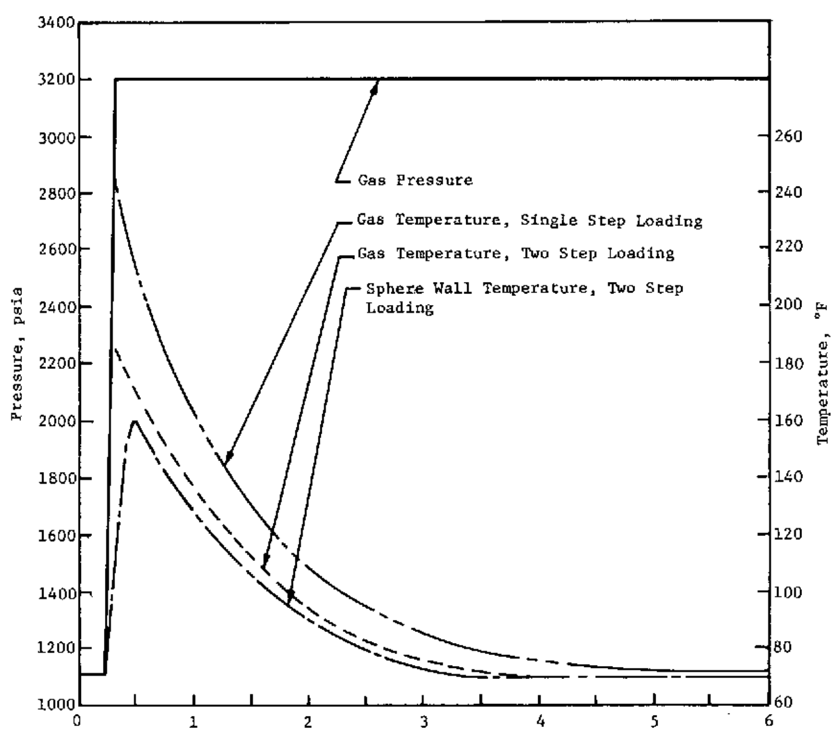


Figure 5-5 Thermal Stabilization Rate for Helium Loading

The airborne helium systems (MPS and APS) will be pressurized on the launch pad from 1100 psig to 3200 psia during the 4-hour period allowed for payload servicing commencing at T-10 hours. Present requirements from the Baseline Space Tug Configuration Definition document require 3200 psia for the MPS and 3000 psia for the APS. Because both the APS and MPS helium systems must be loaded concurrently, it is recommended that both systems be loaded to the same pressure as discussed in para 4.3.2.

4.3.2 Recommended Modifications

Increase the pressure of the Tug APS helium system from 3000 psia to 3200 psia. This change would allow both APS and MPS systems to be loaded concurrently to the same pressure with a common pressure control panel as shown in Figure 5-6. This minimizes system and operations complexity and reduces cost by having only one Tug ground helium pressurization system.

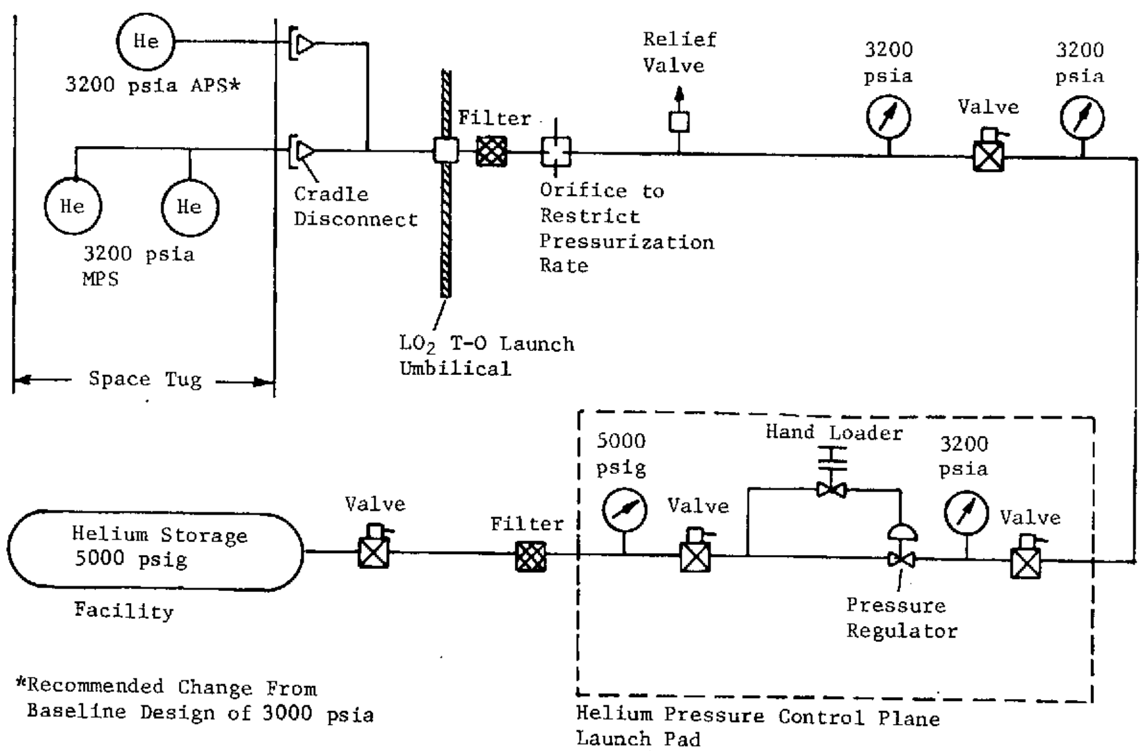


Figure 5-6 Space Tug Helium Servicing Schematic

The APS system was selected for change over the MPS since the APS requires less helium and the impact caused by increased pressure has a minimum impact on Tug performance because of the increased tank weight to accommodate the higher pressure. The higher pressure would also provide a contingency for the APS helium requirement. If the APS storage tank and regulators are selected from existing flight qualified hardware, there could be no impact to accommodate the higher pressure.

4.4 TUG FUEL CELL REACTANT SERVICING

4.4.1 Function Description

The Tug fuel cells will be serviced on pad during the four hour period allowed for payload servicing commencing at T-10 hours. The Tug is located in the Orbiter bay with the payload bay doors open.

The cryogenic fluids are first serviced on the Orbiter by pressure transfer from the storage dewars through 1.5 inch diameter vacuum jacketed lines. Following Orbiter servicing, the Tug dewars will be loaded and pressurized. The LH_2 and LO_2 systems provide simultaneous servicing of the Orbiter vehicle fuel cell dewars and the Tug vehicle fuel cell dewars. The servicing approach is to initiate transfer on one system and verify no leakage and proper operation before bringing up the other system. A timeline with major events for servicing both the Orbiter and Tug fuel cells is shown in Figure 5-7.

It is assumed the Tug fuel cells will not be activated until orbit is achieved and before Tug deployment. It may be possible to pressurize the Tug dewars in orbit; however, heater power considerations suggest that the Tug fuel cells dewars be pressurized on the ground.

4.4.2 Design Assumptions and Recommended Modifications

For servicing of the fuel cell reactant fluids, it is assumed that the airborne tanks are double walled vacuum jacketed dewars capable of storing 22 lb LH_2 and 178 lb LO_2. It is also assumed that the tanks have capacitance probes and, for loading purposes, are similar to the Orbiter fuel cell dewars and those used on Apollo.

From previous studies, a schematic of the proposed facility to service the Orbiter fuel cells with LH_2 is shown in Figure 5-8. The LO_2 system is similar. This information, received from NASA KSC, represents a new facility with the storage dewars located on opposite corners of the service tower at the 80-ft level on the west side. Figure 5-8 presents the modifications required to accommodate servicing the Tug from the same facility. Again, modifications to the LO_2 system are similar.

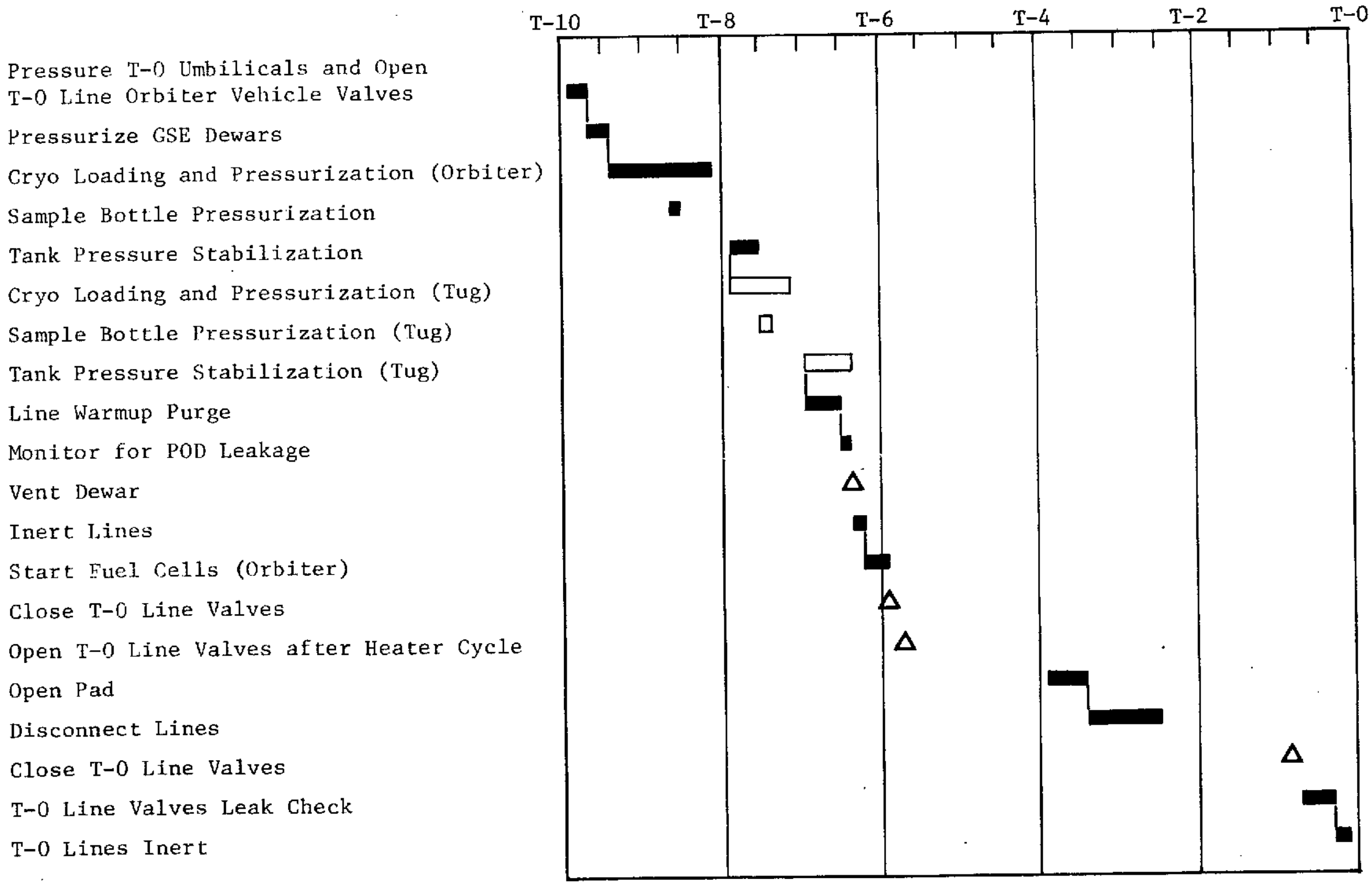


Figure 5-7 Orbiter and Tug Fuel Cell Servicing Timeline

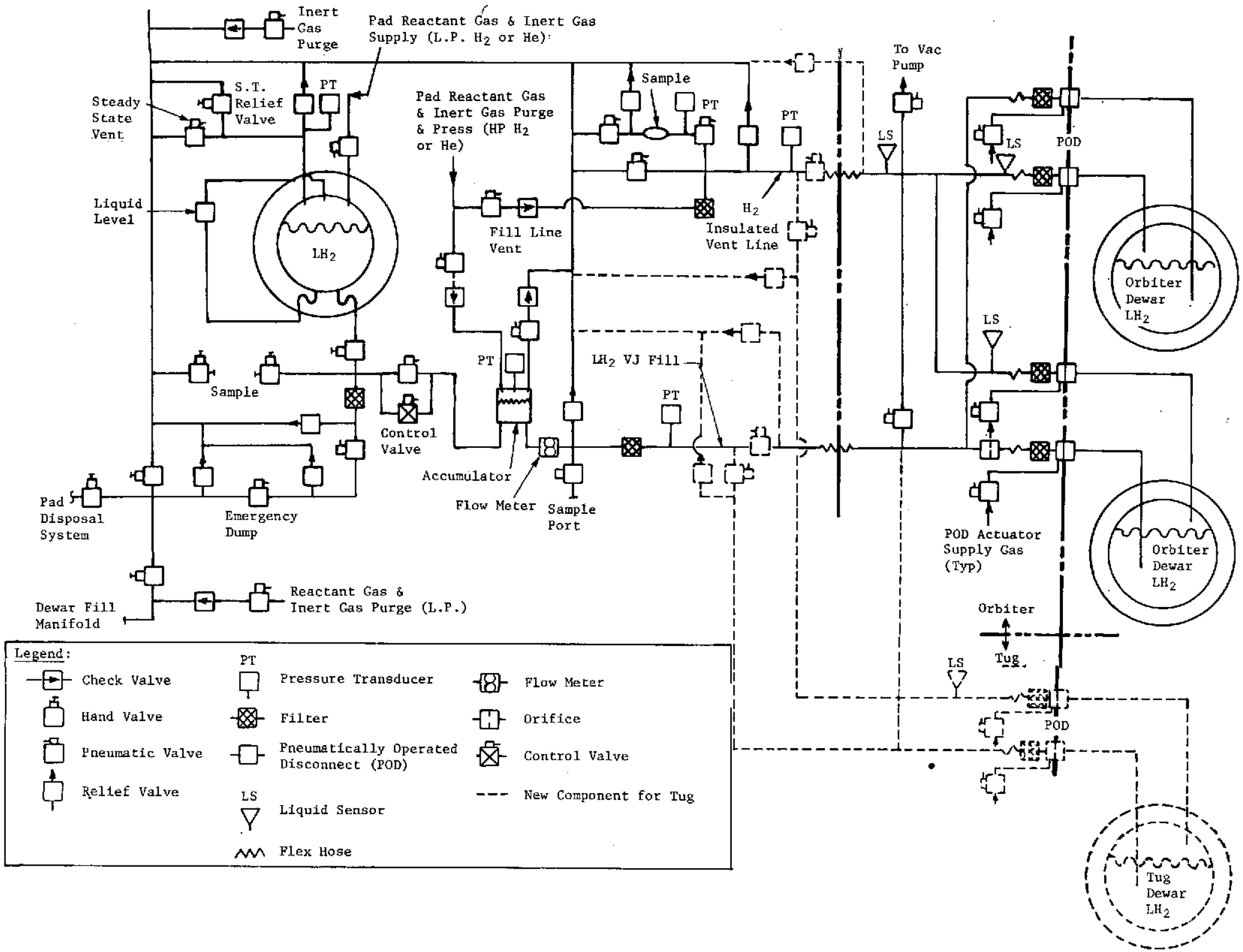


Figure 5-8 LH_2 System Schematic for Fuel Cells

The mobile GSE used to service the Apollo fuel cells was also considered; however, with slight modifications, the new facility could accommodate both systems, requiring less maintenance and operations with only one facility.

4.5 TUG MLI PURGE

4.5.1 Function Description

During prelaunch, ambient helium from ground supply is supplied as soon as the Tug is installed in the orbiter to purge the MLI which is contained in a purge bag. The helium is supplied as soon as the Tug is installed in the orbiter at approximately T-20 hr until launch. At liftoff, the purge is terminated and the evacuation valves are opened to vent the insulation system. Upon Orbiter reentry, the purge bag is repressurized from the helium supply located on the Tug adapter.

The MLI purge vent is an addition to the T-0 umbilical panel shown in the Payload Accommodations Document. The purge vent may contain propellant vapors caused by stage leakage, and was therefore not vented into the payload bay. Consideration was given to dumping the MLI purge vent into the respective GO_2 and GH_2 vents; however, during loading and topping of the main tanks, a back pressure would be imposed on the purge bag. The bag, as has been currently defined, is capable of only very low differential pressure. The back pressure would require a higher purge bag supply pressure that may be incompatible with the purge bag capability.

Under normal ground turnaround operations, the MLI remains sealed in the purge bag in a helium atmosphere. In the event this protection is removed and the MLI is exposed to ambient atmosphere, it is necessary to redry it by means of a hot N_2 purge cycle for a period of time followed by a helium purge.

4.5.2 Recommended Modifications

The Multilayer Insulation (MLI) system for the main propulsion LO_2 and LH_2 propellant tanks is assumed to be configured as shown in Figure 5-9 with dedicated MLI purge vents.

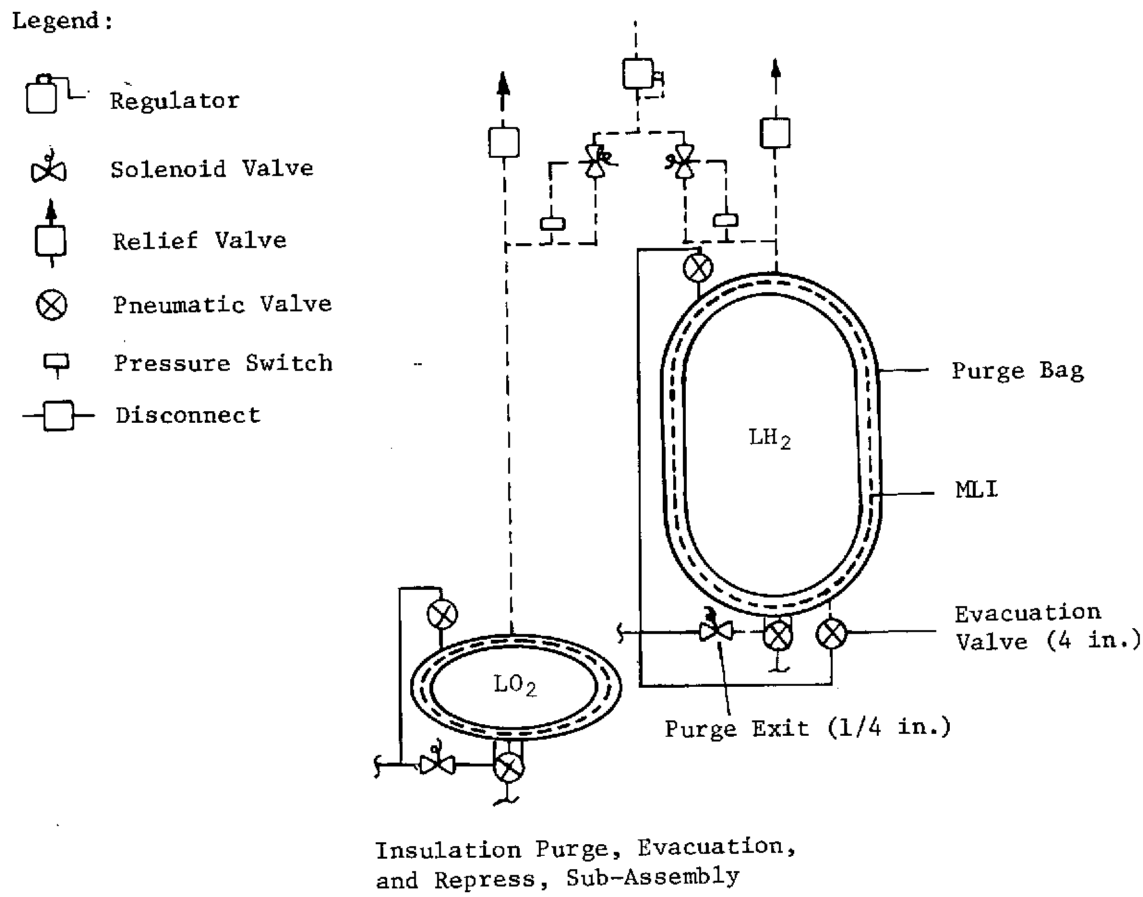


Figure 5-9 MLI Purge System Schematic (Proposed)

4.6 TUG MPS PROPELLANT LOADING

4.6.1 Function Description

The Tug main propellant system will be loaded with cryogenics concurrently with the loading of the Shuttle cryogenics. This will be accomplished on-pad with Shuttle loading starting at T-2 hours and requiring 75 minutes for completion. Tug loading will be accomplished within this time span as shown in Figure 5-10. The Tug loading sequence is dependent on the Shuttle loading sequence and cannot be finalized until the Shuttle loading sequence is totally defined. The Shuttle loading sequence shown is based on previous studies performed for NASA and updated to reflect current design loading requirements of 75 minutes for the External Tanks.

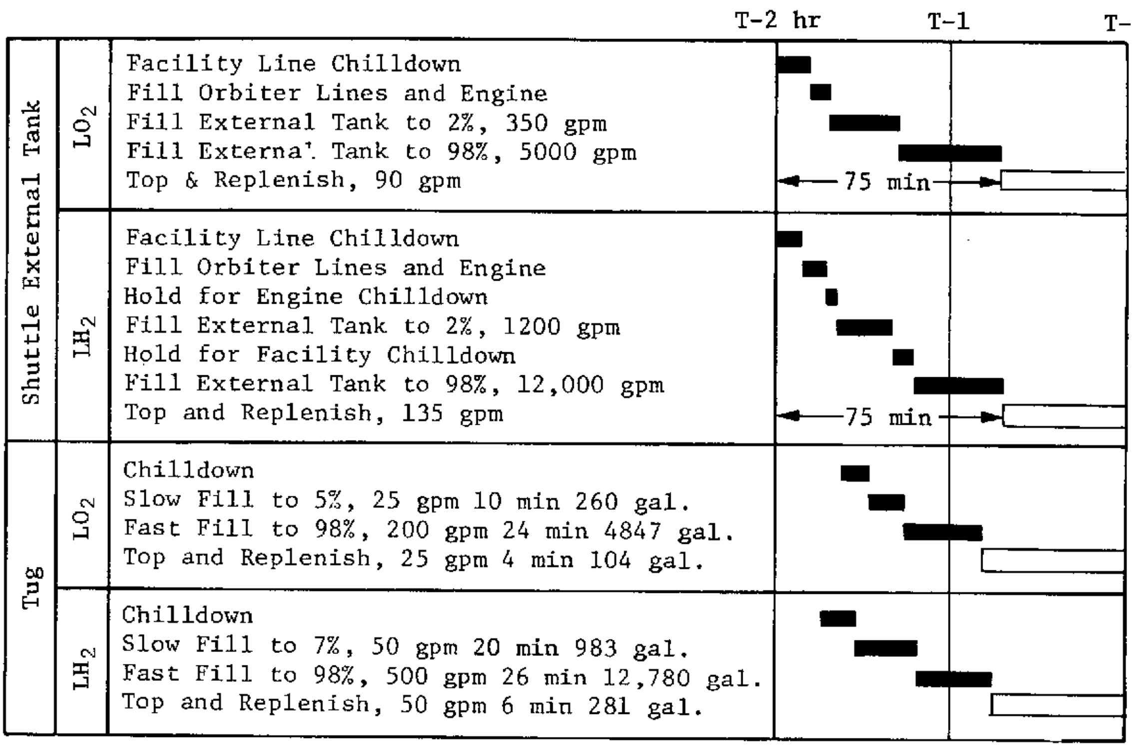


Figure 5-10 Simultaneous Shuttle/Tug Propellant Loading

The Tug loading sequence is arranged such that the Tug flow starts after Shuttle flow is initiated and stops before the Shuttle flow is terminated. Each event for Shuttle and Tug loading is scheduled so as not to happen simultaneously with another loading event. This will provide maximum operational visibility and maximize the safety considerations.

4.6.2 Design Assumptions

The propellant loading system shown in Figure 5-11 was assumed for the purpose of this study. It is based on recommendations from a previous NASA funded study.* The system shown is for liquid oxygen. The liquid hydrogen system would be similar.

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*Report No. GDCA-BN273-003, "Space Tug Launch Site Service Interface Study"

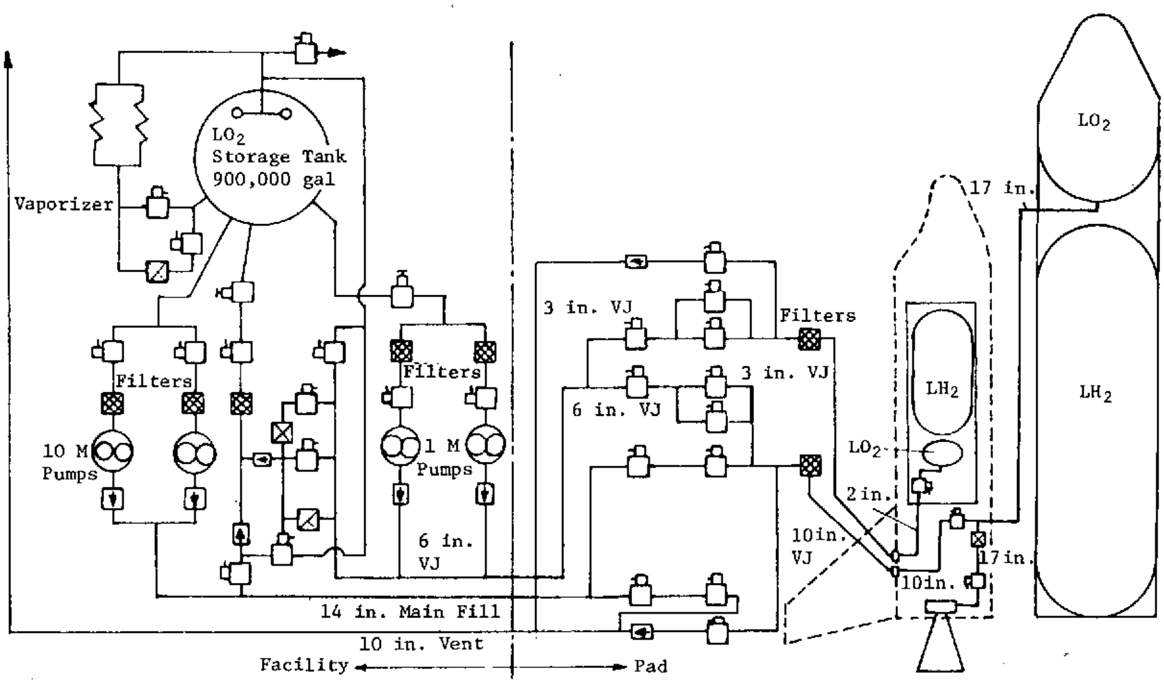

Figure 5-11 Liquid Oxygen Storage and Transfer System

It is assumed that separate Shuttle and Tug cryogenic propellant loading systems will be used based on the following considerations:

1) Pressure surges in the Shuttle loading system will not be imposed on the Tug MPS.

2) Propellant flow can be controlled better for the Tug.

3) Less onboard weight penalty with fewer vehicle components and accessibility requirements.

4.7 TUG FLUID SERVICING PANEL(S) REQUIREMENT

4.7.1 General Description

From the Space Shuttle System Payload Accommodations Document Volume XIV Rev C, fluid and electrical services for the cryogenic Tug are provided by GSE through the T-0 launch umbilicals and the payload umbilical. As stated in the above document (page 5-3), "Ground services required to preclude a hazardous condition or to safe the payload, in the event of launch abort is required subsequent to T-4 hours, shall be assigned to the T-0 launch umbilical panel. Ground services required up to T-4 hours shall be assigned to the prelaunch umbilical." From the standpoint of of timelines, the fuel cell could be serviced through the pre-launch umbilical; however, this would place both the LO_2 and LH_2 dewar servicing through the same panel. For safety considerations, it is desirable to separate LO_2 and LH_2 servicing panels as provided by the T-0 launch umbilicals.

4.7.2 Recommended Modifications

Add provisions to the T-0 launch panels (not currently shown in the Payload Accommodations Document) to provide for fuel cell servicing and for MLI purge. The service requirements for the T-0 launch umbilicals to accommodate the cryogenic Tug are shown in Figure 5-12.

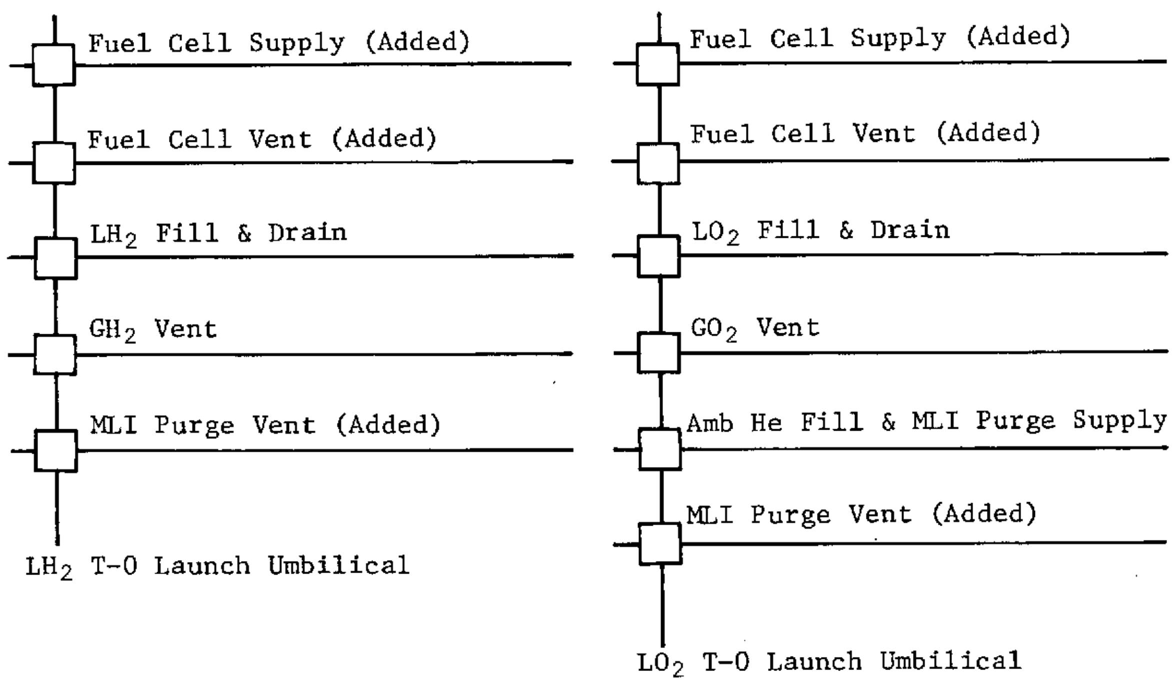

Figure 5-12 Recommended T-0 Launch Umbilical Panels

Addendum 6 Factory Clean Processing

MCR-74-488
NAS8-31011 Addendum 6 January 1975

TUG PROCESSING IN A FACTORY CLEAN ENVIRONMENT ANALYSIS

Prepared by

Jerry J. Gallentine/K. O. Roebuck
Test Integration

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1.0 INTRODUCTION

The purpose of this study is to determine the Tug cleanliness requirements during ground processing of the Tug at the launch site. As part of this study, a specific recommendation will be made as to whether the Tug should be first cleaned in a 100K class clean room before refurbishment and checkout and then processed in this environment, or if it should be refurbished and checked out in a controlled factory environment and then cleaned just before mating with a spacecraft, or placed in the payload canister.

The steps required for normal Tug refurbishment and checkout include:

1) inspection and checkout to the line replaceable unit level;

2) required structural rework;

3) optical check for structural alignment;

4) line replaceable unit removal and replacement;

5) cleaning operations; and

6) storage of Tug until mission assignment.

2.0 GENERAL TUG CLEANLINESS COMPATIBILITY

2.1 TUG CLEANING

A visibly clean Tug will be cleaned by a gross cleaning process. Gross cleaning will remove contaminants such as weld and heat treat scale, corrosion, oxide films, oils, grease, shop soil, fuel and carbon deposits, residue from burned surfaces, loose particulate, and deposition from outgassing. This type of cleaning is considered a normal shop process and usually does not require special environmental controls, packaging, handling, or storage beyond accepted good practice that will not degrade the quality of the Tug.

The following types of cleaners will be used for removing gross forms of contamination:

1) acid cleaners,

2) alkaline cleaners,

3) mild alkaline cleaners and detergents,

4) organic solvent cleaners,

5) tap water and deionized water,

6) neutralizing and passivating solutions,

7) mechanical cleaning.

The specific cleaner used and method of cleaning will be specified in detailed cleaning procedures to be prepared at a later date.

2.2 COMPATIBILITY WITH ORBITER PAYLOAD BAY

The Orbiter payload bay will be visibly cleaned and purged in accordance with NASA Requirement Document JSC 07700 Volume XIV before loading a payload. This cleanliness condition is equivalent to a class 100K clean room. Specifically, the internal surfaces of the payload bay envelope will be cleaned to a visibly clean level as defined in JSC Specification SN-C-0005. (Visibly clean is defined as the absence of all particulate and nonparticulate visible to the normal unaided, except corrected vision, eye. Particulate is identified as matter of miniature size with observable length, width, and thickness. Nonparticulate is film matter without definite dimensions.) In addition, the payload bay will be continuously purged with nominally class 100, guaranteed class 5000 (HEPA filtered) air per FED-STD-209B, which will contain less than 15 parts per million hydrocarbons, based on methane equivalent. The air within the enclosure will be maintained at 70 ± 5° and 45 ± 5% relative humidity. This condition will be maintained through payload loading and all subsequent launch preparation operations.

The level of cleanliness maintained at preflight on the payload and payload bay will be retained through launch and orbital insertion. By visibly cleaning the Tug surfaces to the level specified in JSC Specification SN-C-0005, the Tug cleanliness will be compatible with the prelaunch cleanliness conditions of the Orbiter payload bay area, and therefore will not degrade its cleanliness.

2.3 COMPATIBILITY WITH SPACECRAFT

The purpose of the Tug is to place designated spacecraft in specific orbits and retrieve certain ones for return to the Orbiter. It is a requirement in performing this mission that the Tug not contaminate the various spacecraft causing degradation of performance ability to meet mission objectives. Table 6-1 shows a compilation of Tug related payloads having specific cleanliness class requirements. It is noted that 17 (the majority of these payloads) are of the 100,000 (100K) class, which is the same cleanliness level environment specified for the Orbiter payload bay.

Table 6-1
Tug Spacecraft Cleanliness Requirements

Spacecraft Cleanliness Level	Number of Spacecraft
100K	17
10K	5
5K	1
1K	1
500	2
Unknown	17

It should be pointed out that this cleanliness specification (100K class clean room) does not relate per se to how clean a payload is. The specification states that there will be a maximum allowable number of airborne particles per unit volume 0.5 micron and larger, or 5.0 microns and larger at a location that will yield the particle count of the air as it approaches a specific "work" location. For example, for a class 100K environment, the particle count cannot exceed a total of 100K particles per cubic foot of a size 0.5 micron and larger, or 700 particles per cubic foot of a size 5.0 microns and larger. However, this particle requirement does limit the number and size of particulate that could possibly be deposited on a critical surface such as an optical surface, spectrographic slits, or contaminant-sensitive component such as an IR detector.

Other particulate contamination concerns of spacecraft are electromagnetic wave scattering, absorption, and emission characteristics of these particles.

For those payloads whose particulate contamination conditions must be controlled to more stringent tolerances than the class 100K level, for example, to air cleanliness classes of 10,000 or 100, the payload contractors will have to provide necessary cleanliness protection, such as protective shrouds.

The Tug will be in compliance with the class 100K environment when visibly cleaned to JSC Specification SN-C-0005.

2.4 SELF-GENERATED CONTAMINATION CONTROL REQUIREMENTS

Contamination control of the Tug and its support equipment (SE) that will be contained in the Orbiter payload bay will be cleaned to meet the required cleanliness condition of the payload bay (100K class equivalent). This procedure includes cleaning all visibly loose contaminants in the Tug, visibly cleaning all surfaces, control of contamination from material outgassing (per NASA Specification SP-R-0022), propellant leakage, mechanical systems operation, and venting of consumables used by the Tug. During flight operations, the Tug main propulsion system and APS exhaust should be constrained not to impinge or be reflected upon the spacecraft, Orbiter, or mission-peculiar equipment.

By cleaning the Tug to a visibly clean condition and incorporating the previously listed constraints, no contamination control problem for the Orbiter payload bay or spacecraft resulting from Tug flights is envisioned.

3.0 CORRELATION OF TUG CLEANLINESS WITH 100K CLASS CLEAN ROOM

The correlation between a visibly clean surface and a clean room class is not directly or measurably related. As discussed previously, a clean room class measurement is the number of particles of a specific size in a specific volume (ft^3 or m^3) measured between the HEPA filter air inlet and the approach to a specified work location.

If the surface of a Tug is visibly clean, there is less chance for particulate to be left on it to be sloughed off later by personnel brushing it or by air currents picking it up, with both type actions generating increased contamination in the air. It should be noted, however, that even in a class 100K clean room environment, after a given time particulates will settle-out on surfaces; therefore, all flight hardware should be covered if left in the clean room for an extended period of time.

In summary, a visibly clean Tug will not increase the amount of particulate in a 100K clean room.

4.0 REFURBISHMENT LOCATION AND TIME REQUIREMENTS

The basic question of this study is to determine when and where, during the ground refurbishment process, the Tug should be cleaned. Should it be refurbished in a factory environment in an as received condition (just returned from a flight mission or as received from the Tug contractor), and then cleaned to the required cleanliness specifications just before mating with a spacecraft or cansiter, or should it be cleaned first, then processed in a class 100K clean room, and continuously maintained in that environment through prelaunch activities?

4.1 FACTORY CLEANING VERSUS 100K CLEAN ROOM

Based on our Viking experience, it has been estimated that about a 30% saving in time can be made in refurbishing and checking out an assembly such as a Tug in a factory controlled environment, compared to a class 100K clean room. It must be emphasized that to go the factory checkout route, clean room type cleanliness around the assembly is sacrificed. However, cleanliness criteria for the Tug per se are not stringent.

In general, both assembly areas will require the same cleanliness discipline such as continuous contamination cleanup, but obviously the class 100K clean room will require more stringent cleanliness procedures.

A summary of the items and functions required for the class 100K environment that make up the 30% longer time for a Tug refurbishment operation as presented in Figure 6-1.

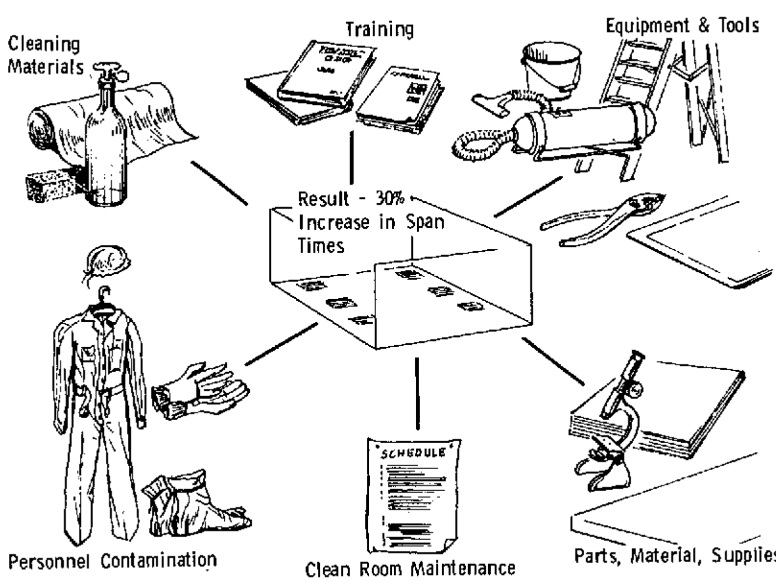

Figure 6-1 Refurbishment Location and Time Requirements

4.1.1 Materials

Cleaning fluids, detergent liquid, sponges, wipers, and gases are controlled to specifications.

4.1.2 Equipment and Tools

Portable and installed equipment used in the clean room will be maintained to a specific cleanliness level. The following equipment is normally required for maintenance and operational functions in the clean room.

4.1.2.1 Cleaning Equipment - Stainless steel waste receptacles and mop buckets, aluminum step ladders, gelatin (T190R52) floor mats, vacuum cleaner with HEPA filter or equivalent, or vacuum cleaning capability with discharge outside of the clean room.

4.1.2.2 Equipment and Tools - Equipment and tools will be maintained to a specific cleanliness level in the clean room. The use of lubricant will be held to a minimum and only approved types will be used. Cleaning of tools and equipment will be accomplished by wiping with a special clean wiper dampened with a specific solvent and/or followed by vacuum cleaning.

Equipment and tools brought into the clean room through the vehicle airlock entryway will be cleaned in the following manner:

1) The item will be blown with filtered air or nitrogen at 30 psi maximum before being brought into the air lock. Contaminations visible after this process will be removed by solvent cleaning (brush or wipe) or abrasive cleaning (wire brushing, etc) followed by repeat air blast cleaning.

2) Once entered into the vehicle airlock entryway, the item will be wiped with a clean wiper dampened with solvent followed by complete and thorough vacuum cleaning.

3) The item and vehicle entryway will be free of visible contamination before the inner door to clean room is opened. This operation is time consuming.

4.1.3 Personnel

Personnel are a major source of contamination in a clean room. To reduce this source of contamination to the maximum extent possible, specific features are provided.

To enter a clean room personnel must first enter a clothes changing room and then proceed through an air lock. Clothing required for use in a clean room includes coveralls, boots, hoods and caps, and gloves. Personnel before entering the clean room change area will remove sweaters, coats, hats, and other types of severe weather clothing or footwear. Shoes will be free of obvious visible contamination (mud, grease, etc).

Personnel upon entering the clean room change area will vacuum their clothes and don clean room clothing except boots. Boots will be donned in the airlock area.

Personnel leaving the clean room will remove their boots in the airlock area and their coveralls, gloves, and head cover in the change area. Coveralls and head covers shall be placed in a polyethylene bag; shoe covers in a separate polyethylene bag. Personnel normally assigned to the area will store their bagged clothing in their locker.

Since personnel enter and leave a clean room several times a day (at the start of the day, mid morning break, lunch break, midafternoon break, and unscheduled exits), a considerable amount of time is consumed in clothes changing.

4.1.4 Parts, Materials and Supplies

Parts, materials, instruments, or supplies will be contained within an acceptable clean room covering made of nonfriable, inert plastic or corrosion resistant material before entry into the clean room. Outer surface of wrapping or covering will be vacuum cleaned before entry.

Paper and paper products (other than approved clean room paper) required for clean room operations will be contained in a suitable container or covered by plastic film when not being used.

Cleaned parts scheduled for entry into the clean room and transported in protective containers or coverings to avoid physical damage, will be removed from the protective media when inside the clean room entryway. If it is necessary for a container to enter the clean room, the outer surfaces of the container will be solvent wiped and/or vacuum cleaned before entry into the clean room.

Any fabrication operation that generates harmful contamination will be performed according to specific procedures.

4.1.5 Clean Room Maintenance Requirements

All surfaces of the clean room area will be maintained in a usually clean condition.

Specific daily and weekly maintenance activities will be performed in accordance with specific procedures.

Personnel working in the clean room will maintain the cleanliness level of their immediate work area and work surfaces by progressively removing contamination as generated or observed. Cleaning will be accomplished by using a clean cloth or sponge followed by a dry cloth wipe and/or vacuum cleaning.

Maintenance personnel are required to be on duty at all times work is being accomplished in the clean room.

4.1.6 Personnel Training

Personnel selected to work in a clean room must be trained for the job. The following factors will be considered in training:

1) Indoctrination must include a thorough acquaintance with the clean room rules, regulations, and procedures.

2) An explanation of the reasons for these stringent regulations must be given.

3) Both individual and team training should be conducted in a simulated clean room.

4) It is advisable that indoctrination and training be extended not only to the immediate level of supervision of the clean room operators but to the next higher level.

NASA has prescribed a minimum course of instruction for all personnel whose activities may bring them in contact with contamination-sensitive articles.

Although a time and motion study has not been conducted on the Viking class 100K clean room to compare the difference in time between test and checkout in this facility versus a controlled factory, it is thought that the 30% value is reasonable. TPF processing time shown in subplan III-A stick-and-ball does not take into consideration this 30% factor, and would increase from 93 to 124 hours. The factory clean stick-and-ball (Fig. 6-2) shows TPF time of 93 hours.

Another consideration in deciding where to conduct cleaning of the Tug and its support equipment (SE) is the availability of clean room space versus number of Tugs and spacecraft to be processed at one time. Since clean room space is limited, it is economically advantageous to refurbish the Tug and SE in a controlled factory area and clean it there just before its integration with the spacecraft. In addition to providing more space for spacecraft preparation, cleaning the Tug in the factory area will reduce contamination maintenance in the clean room facility and protect other spacecraft located in the clean facility.

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Examples of contamination particulate sources encountered during the refurbishment process include release of particles lodged in cracks when the access panels are removed, structural rework, inspection and checkout to the line replaceable unit level, and removal and replacement of line replaceable units. In addition, it is probable that paint in the vicinity of the APS and main engine will have blistered during engine firing operations and be subject to spalling or be sloughed off by workmen brushing against the surfaces during refurbishment.

Additional reasons why the Tug should not be cleaned in the clean room include:

1) tools and fixtures used for Tug refurbishment would not have to be cleaned to a clean room condition;

2) removing outgassing deposition on the external surface of the Tug could be a complex operation requiring large use of solvents and abrasive materials that would not be compatible with a clean room;

3) contaminated thermal control paint removal could require scraping, sanding, or other processes not compatible with maintaining a clean room environment.

These examples and others are contained in Table 6-2 which is a matrix showing the most probable contamination sources the Tug could encounter, and the recommended location for cleaning during the Tug ground processing.

C-2

Table 6-2 Comparison of Tug Cleaning in Factory vs Class 100K Clean Room

Contamination Source	Preferred Cleaning Location Factory (Controlled Area)	Class 100K Clean Room
1. Residual Contamination from Fabrication	Chips, metal filings, etc that vibrate out could be removed at either location	Chips, metal filings, etc that vibrate out could be removed at either location
2. Suspended Contaminant Affecting:		
a) Tools, Fixtures, Work Surfaces	Could be vacuumed and wiped down more easily	Would require high maintenance effort/clean room procedures
b) Fallout Impingement		Air inherently cleaner due to clean room filtering
3. Personnel Generated	Could be minimized	Area inherently cleaner due to clean room procedures
4. Work Generated	Debris generated would be the same at either location	Debris generated would be the same at either location
5. Tug Self-Generated	Debris generated would be the same at either location	Debris generated would be the same at either location
6. Flight Environment		
a) Payload Bay Particulate Ingestion	Contamination removed more efficiently without clean room procedure restriction	
b) Orbiter RCS and VCS Impingement	Dirty operation requiring scraping and sanding plus special solvents and repaint	
c) Tug APS/Main Engine Impingement	Dirty operation requiring scraping and sanding plus special solvents and repaint	
d) Outgassing	Deposition areas that could require scraping, sanding, etc plus special solvent and repaint	
e) Thermal Paint UV Degradation	Dark paint areas that could require scraping, sanding and repaint	
7. Anomaly/Repair		
a) Mechanical	Contaminant removed more efficiently without clean room procedure restrictions	
b) Hydraulic	Contaminant removed more efficiently without clean room procedure restrictions	
c) Electrical	Contaminant removed more efficiently without clean room procedure restrictions	
d) Structural	Contaminant removed more efficiently without clean room procedure restrictions	

5.0 TUG PROGRAM CONTAMINATION CONTROL CONSIDERATIONS

5.1 DESIGN DEVELOPMENT/REFURBISHMENT

To eliminate contamination that might constitute a hazard or interfere with the operational phase of the Tug or spacecraft, contamination control is considered at the Tug design/development stage. All too often, contamination control procedures are not developed until after a failure or degradation of data has taken place. At this stage, design/development features are very costly to be incorporated into the design. Those features to be considered are:

1) minimize or eliminate sources of contaminant generation. An example is the selection of nonmetallic materials for the Tug in accordance with NASA Specification SP-R-0022 to minimize the effects of offgassing and outgassing;

2) render the Tug least susceptible to contamination;

3) facilitate contamination removal and monitoring during manufacturing and later cyclic refurbishment of the Tug.

To develop an effective contamination control design, the Tug designer must be aware of more than just the function and reliability requirements; he must also be aware of the following factors of the total Tug life:

1) Cleanliness requirements;

2) Manufacturing/refurbishment and processing environments;

3) Manufacturing/refurbishment processes;

4) Test procedures and equipment;

5) Operational use and storage conditions.

A further breakdown of design/development considerations for Tug contamination control follows:

1) Materials - All nonmetallic materials used on the Tug should be selected in accordance with NASA Specification SP-R-0022 to control outgassing. All materials should be selected based on contamination control including corrosion, wear products, shedding, and flaking.

2) Configuration - Consideration should be given to accessibility to surfaces and sensitive areas, mating of materials, generation of contaminants, and protection of parts for contamination control.

3) Fabrication - During the fabrication process, the following contamination control concerns should be considered:

   a) Casting residues and entrapped gases;

   b) Molding flash, residue, and mold wear products;

   c) Forming, drawing and extrusion burrs, lubricants, release of compounds, particles, and scales;

   d) Machining burrs and chips, capillary traps, coolants, and cutting oils;

   e) Chemical milling etch residue;

   f) Plating scale, flaking, and residue;

   g) Heat treat scale, silica, and liquids;

   h) Cleaning effects on material, drying, and residue;

   i) Polishing oils, polishing compounds, chemical residue, dust, and oxides;

   j) Tools, equipment, and personnel causing dirt and oil deposits, product wear, personnel contaminants, and airborne contaminants.

4) Assembly Processes - During assembly and recycle refurbishment the following contamination control concerns should be considered:

   a) Migration and transfer of contaminants from mating assemblies, tools-jigs-fixtures, work surfaces, personnel and environment during product flow and assembly sequence;

   b) Generation of fragments, chips, shedding, flux residue, fumes, and oxides due to fastener operations (riveting, bolting, and welding).

5) Test and Inspection - Generation of flaking, shedding, oil, dirt, and abrasion products caused by the use of test equipment and fixtures.

6) Storage - Packaging considerations should include the proper selection of containers, wrapping materials, cushioning materials, desiccants, and barriers. Environmental considerations should include temperature, humidity, pressure, shock, and vibration.

An absolute measurement or definition of the degree of cleanliness required for a specific case is frequently impracticable or impossible. The alternative is to establish minimum product performance levels. Performance levels can be developed for:

1) production processes;

2) appropriate levels of assembly of products;

3) controlled areas and facilities (not necessarily clean rooms);

4) cleaning methods;

5) finished products;

6) other activities where indication of a cleanliness level is required.

If performance levels are established in lieu of cleanliness levels, they must be commensurate with the performance requirements of the Tug. Control methods and monitoring techniques must be employed to maintain uniform and consistent operations, and to assure adequate levels of contamination control at all times. These control methods and monitoring techniques will be delineated in the Tug refurbishment contamination control plan.

5.2 ON-ORBIT OPERATIONS

The major source of on-orbit contamination to the payload is the Orbiter. Orbiter vents and filters must be designed to minimize deposition and particulate contamination for launch and reentry. Vent closing and opening must also be timelined to minimize contaminant ingestion.

The Tug main engine and APS produce little or no contaminant by-products. The Orbiter RCS and VCS produce MMH nitrate, which is a brown, viscous material that can contaminate the spacecraft and Tug thermal control surfaces. Maximum use of the APS and minimum use of the Orbiter RCS and VCS should be programmed for Tug deployment and retrieval during mission operations.

Spacecraft developers requiring areas cleaner than class 100K around their spacecrafts will be responsible for the provisions of this environment for all phases of the mission including Orbiter prelaunch and launch and Tug operations.

Both active and passive thermal control systems will be used on the Tug. Based on a Tug mission duration of five days for up to 20 missions, the white thermal control paint could turn brown because of contaminant deposition and high energy radiation. Refurbishment of the thermal control surfaces will be required on a schedule compatible with the thermal control design considerations.

Dumping liquids overboard from the Orbiter should be timelined so as not to contaminate the spacecraft or the Orbiter.

Although the exhaust products of both the Tug main engine and the APS are not contaminants, surface areas in the vicinities of the engine nozzles will surface blister and spall when the engines are fired.

Surface material selection should be carefully considered and either cleaning or replacement of these surfaces should be programmed into the refurbishment cycle on a scheduled basis.

Another area of particulate contamination control that should be addressed during cleaning in the refurbishment cycle is the removal of that contamination that was trapped in areas inaccessible for cleaning during fabrication, but which may become accessible after flight because of vibration of the Tug. If not removed, this material could possibly shake out during flight operations and depending on where it exits from the Tug, could possibly lodge on the spacecraft where it could degrade its operational performance.

5.3 ANOMALY IMPACT ON TUG CLEANLINESS REQUIREMENTS

Based on multiuse of the Tug for orbital missions, a sizeable maintenance program with inherent contamination problems accompanying these operations could occur. Examples of Tug system anomalies that could cause contamination of the Tug include:

1) hydraulic system leaks and spills;

2) coolant system leaks and spills;

3) propulsion system leaks and spills;

4) pneumatic system leaks;

5) line replaceable units failures requiring major rework.

Flight operations that could affect Tug cleanliness requirements include rendezvous contamination from the Orbiter during deployment and retrieval. Orbiter launch and reentry payload bay contaminant ingestion could occur during launch when the SRBs are staged which could cause an external positive pressure surge to blanket the payload bay vents with the possibility of forcing some contaminants into the payload bay. During reentry, the payload bay vents are actively controlled and are closed during the highly contaminating phase of reentry. However, contaminants lodged at the inlets of the vents or in the vicinity of the vents during this phase of the Orbiter reentry could be forced in and deposited on the Tug.

These types of anomalies and contamination conditions could be of such a major consequence that it may be impractical to process them in a class 100K clean room environment.

6.0 FUNCTION FLOW

6.1 RESOURCE REQUIREMENT DELTA

The Tug ground operations flow is shown in Figure 6-3. This flow identifies the operations required for processing the Tug in a "factory clean environment." The operations are essentially the same as those required for "100K clean processing" which are identified in subplan A. The highlighted areas identify changes from the "100K clean" processing flow.

Function Description Data Sheets have been prepared for each of the new/modified functions and are contained in Appendix A.

There were no changes to GSE, software, or maintenance requirement data sheets because of processing in the factory clean environment.

The Facility Requirement Data sheets change by removing the requirement to process in a 100K environment. One additional facility requirement was identified and that was a 100K equivalent clean room to support spacecraft integration and checkout.

The cost comparison of activating a 100K clean or a factory clean processing facility is contained in subplan D, Tug Site Activation. These figures show that it is cost effective to process in a factory clean environment. In addition, analysis of the stick-and-ball chart shows that the time required to accomplish functions are the same; however, our Viking experience has shown cleanliness procedures add 30% to the operation's time. This 30% increase would add 31 hours to time in TPF for 100K processing.

6.2 MINIMUM CLEANING OF TUG

By definition a 100K class clean room facility contains no more than 100K particles over 0.5 microns and 700 particles greater than 5.0 microns in a cubic foot volume measured as the air approaches a specific work area during work activity. A visibly clean Tug when placed in a 100K class clean room will not degrade its cleanliness level if particles are not generated from the Tug because of personnel working on it. More specifically, if no skin panels or covers are removed and the Tug is not rotated or shaken while in the payload clean room, the Tug will not increase the particulate count in the air of the clean room. From a practical standpoint, some particulate will be generated during the

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attachment of the Tug to the spacecraft and the connecting and disconnecting of integration test cabling. By the enforcement of contamination control discipline during these operations, particulate generation can be minimized to not compromise the clean room standards. Therefore, if required, the Tug could be mated and the Tug/spacecraft checked out in the spacecraft facility.

During prelaunch and postlaunch activities when the Tug and spacecraft are in the Orbiter payload bay in an equivalent 100K clean room environment, the area around the spacecraft should remain at the 100K cleanliness level even though some particulates might possibly sift out from the Tug. This clean condition should exist for the spacecraft because of the purge geometry and cleanliness level. The continuous purge of nominal class 100, guaranteed class 5000 (HEPA filtered) air into the payload bay will be moving from the front of the payload bay back over, first the spacecraft and then the Tug after which it is exhausted out the aft end of the payload bay.

6.3 POSTLANDING OPERATIONS

After the Orbiter lands, the payload bay clean air purge will commence as soon as the purge system can be connected to the Orbiter ($\sim$30 min). The Orbiter will be allowed to cool down for approximately 2 hours before it will be taken inside the Orbiter Processing Facility (OPF). Approximately 15 hours later, the payload bay doors will be opened and the payload removed from the Orbiter. Depending on the contamination sensitivity of the payload, cleanliness handling precautions, including use of portable clean rooms for payloads requiring this type handling, will be observed. For Tug payloads, the Tug will be disassembled from the spacecraft in the OPF and transported to the Tug Processing Facility for refurbishment processing.

The cleanliness condition of the Tug after return from flight will be dependent on launch, on-orbit and reentry and unloading contamination levels. In addition, self-contamination will probably have occurred because of paint blistering and spalling around the engine exhaust areas, particulates shaken out from areas that were inaccessible for prelaunch cleaning, and from possible fluid leaks from Tug operational systems.

Different levels of maintenance activities will be scheduled for the returned Tug dependent on the number of hours (missions) it has been operated, new modification kits to be installed, and operational malfunctions requiring repair. Some operations could cause excessive contamination of the area around the Tug and, if in a "clean room," could cause the clean room to be shut down for cleaning.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

7.1.1 Compatibility with Orbiter Payload Bay

By visibly cleaning the Tug surfaces to the level specified in JSC Specification SN-C-0005, the Tug cleanliness will be compatible with the prelaunch cleanliness conditions of the Orbiter payload bay area and therefore will not degrade its cleanliness.

7.1.2 Compatibility with Spacecraft

When visibly clean, the Tug will be considered to be compatible with the Class 100K clean spacecraft. For those spacecraft requiring a more stringently controlled environment than Class 100K cleanliness, the spacecraft contractor will be responsible for furnishing the clean room condition by furnishing a portable clean room, shroud or bag.

7.1.3 Self-Imposed Contamination

By designing in contamination cleaning features such as cleaning accessibility, selection of materials to reduce outgassing and imposing flight constraints, such as nonimpingement of engine plumes on the payload and visibly cleaning, no contamination control to the spacecraft and Orbiter payload bay is envisioned as a result of flying the Tug.

7.1.4 Refurbishment Location and Time

Our Viking experience has shown that it will take about 30% longer to refurbish the Tug in a class 100 clean room.

7.1.5 Contamination Control Constraints

At the start of Tug design/development, consideration must be given to contamination control. Operational contamination control constraints must be imposed to reduce contamination to the payload and Orbiter and to reduce ground refurbishment cleaning operations.

7.1.6 Anomaly Impact on Tug Contamination Control

Based on multiuse of the Tug for orbital missions, a sizeable maintenance program with inherent contamination problems accompanying these operations could occur. These contamination conditions could be of severe enough magnitude that cleaning operations in a clean room would be costly and time consuming.

7.2 RECOMMENDATIONS

The Tug is not critically sensitive to contamination with exception of specific components such as the star tracker that could be protected locally. In addition, since clean room facility space and refurbishment time will be at a premium, it is recommended that the Tug be cleaned and refurbished in a controlled factory facility.

This factory type facility should be designed with a view toward high standards of shop cleanliness such as "slick" surface floors, walls, and ceilings where particulate cannot settle and later recirculate due to work activities and air circulation. Extensive janitorial help should be provided during work activities to remove any accumulated contamination. All work personnel should be trained and disciplined (in accordance with a Ground Contamination Control Plan) to clean up any contaminant they generate during specific refurbishment activities.

7.2.1 Tug Wipe Down

It is recommended that the Tug external surface be wiped down as soon as it is brought into the factory-type refurbishment facility so that particulates will not fall into the Tug when panels and doors are removed for maintenance. This cleaning activity will reduce particulates in the vicinity of the Tug because of personnel and support equipment rubbing against the Tug during work activities.

During the refurbishment activities as specific maintenance work is accomplished inside the Tug, the personnel accomplishing the work should vacuum the area and, where visible contaminants can still be seen, wipe the area down in accordance with prescribed procedures contained in the Contamination Control Plan. At completion of the refurbishment process, the accessible internal compartments of the Tug should be inspected for contamination. If contamination is evident, it should be removed in accordance with prescribed cleaning procedures. Following the internal inspection, the Tug should have the external surface cleaned to a visibly clean condition in accordance with prescribed procedures. The Tug should then be enclosed in a protective bag, placed in a temperature and humidity controlled environment for storage.

7.2.2 Spacecraft Mate

It is recommended that the spacecraft be mated with the Tug in the factory controlled area. The spacecraft should be placed in an equivalent class 100K clean room for Tug to spacecraft integration and checkout. This room, which would be above the Tug, would have a circular removable door in its floor that could be removed for the mating operation. A seal would be located around the periphery of the door opening to assure maintaining the clean environment of the enclosure. Immediately on completion of integration and checkout, separate environmental covering should be placed over both the spacecraft and Tug for movement of the payload to the final Tug cleaning location.

An alternative would be to move the Tug into the clean payload launch preparation area for integration and checkout activities with the spacecraft. Since there will have been no air stringent (HEPA filter) particulate control in the factory environment, a final wipe down of the external surface of the Tug should be accomplished after the Tug is unbagged in the payload clean room and before its integration with the spacecraft.

7.2.3 Contamination Control Plan

A Contamination Control Plan for cleaning and maintaining cleanliness during the ground processing of the Tug is necessary for the program. Without a specific plan, a cleanliness discipline could not be maintained to keep the Tug clean after its cleaning operation and from degrading the cleanliness of other hardware during prelaunch, launch, and on-orbit operations. An outline for a Contamination Control Plan to minimize contamination during the Tug ground processing operations follows.

1) Design Requirements - Determine cleanliness level and sensitivity of product. Prescribe contamination limits by design drawings or specifications.

2) Product Design Review - Review the design of the assemblies in terms of contamination sensitivity and ease of cleaning during the ground refurbishment cycle.

3) Processes and Controls - Develop processes and controls to ensure cleanliness of the product and its support equipment during manufacture of parts, components, assemblies, and materials.

4) Subtier Contractors - Outline method for imposing contamination control requirements.

5) Quality Control - Detail and comply with QC procedures, sampling plans, etc.

6) Product Protection - Provide method for product protection to maintain required cleanliness level.

7) Personnel - Outline methods for personnel training, motivation and control.

8) Post Mate - Specify procedures for checkout, storage, transport, and installation of the payload with the Orbiter to assure maintenance of the required cleanliness control.

7.2.4 Factory Clean Canister

Perform trade study to determine feasibility of transport Tug/spacecraft to launch pad in a factory clean canister.

7.2.5 Multiple Tug Cleaning

Perform a study to drive out problems associated with cleaning the Tug up to 20 times in support of the Tug missions.

Addendum 7 WTR Tug Launches

MCR-74-488
NAS8-31011

Addendum 7 January 1975

IMPACT OF TUG LAUNCHES AT WTR

Prepared by

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Systems Engineering

CONTENTS

1.0 INTRODUCTION

Since the summer of 1973, the predicted Tug traffic from WTR has progressively dwindled as shown in the recent WTR Tug traffic evolution presented in Table 7-1. The current WTR traffic is one or two launches per year.

Table 7-1 WTR Tug Traffic Evolution

	84	85	86	87	88	89	90	91
Summer 73								
NASA	4	6	4	6	4	6	4	--
DOD	9	7	13	8	12	8	8	--
Total	13	13	17	14	16	14	12	--
January 74								
NASA	4	1	1	2	2	2	2	2
DOD	4	5	4	4	3	5	3	5
Total	8	6	5	6	5	7	5	7
March 74								
NASA	4	1	1	2	2	2	2	2
DOD	0	0	0	0	0	0	0	0
Total	4	1	1	2	2	2	2	2
September 74								
NASA	2	1	1	1	1	1	2	1
DOD	0	0	0	0	0	0	0	0
Total	2	1	1	1	1	1	2	1

The trade study presented here determines the cost to acquire and support a Tug launch capability at WTR (maximum of 2 launches per year), and compares this with the mission cost penalty incurred if the WTR launch capability is not provided.

The present mission scenario includes the following traffic from WTR from CY 1984 through 1991:

1) Environmental Monitoring NN/D (EO-56); 4860 lb; orbit: 900 x 900 n mi at 103 deg inclination; 6 launches and 5 retrievals.

2) TIROS EO-6 (EO-12); 4740 lb; orbit; 900 x 900 n mi at 103 deg inclination; 1 launch and 1 retrieval.

3) Explorer - Upper Atmosphere PHY-1B (AP-01); 2004 lb; orbit: 140 x 1900 n mi at 90 deg inclination; 2 launches and 2 retrievals.

This results in a WTR traffic rate of one or two launches per year (Table 7-1) as compared to about 25 per year at ETR. EO-12 and EO-56 can be launched from ETR using kick stages; however, they cannot be retrieved.

The WTR costs include the additional GSE, facilities, crew size, fleet size, and transportation to acquire and support the current identified traffic from WTR. The mission cost penalty (without WTR) considers the added cost of kick stages and the difference between refurbishment costs of retrieved spacecraft and the cost of new spacecraft.

The study is based on data presented in References 1 and 2 to the extent possible.

2.0 GROUND RULES AND ASSUMPTIONS

The following ground rules and assumptions are based primarily on data presented in References 1 and 2:

1) A common Tug Processing Facility (TPF) is available at ETR to support both ETR and WTR launches.

2) The Payload Preparation Room (PPR) and Payload Changeout Room (PCR) are available for Tug use at WTR.

3) The ETR launch rate is one every two weeks. The maximum launch rate at WTR is two per year.

4) WTR is assumed to be an alternative landing site for ETR launches; therefore, the GSE to handle, safe, and transport the Tug at WTR is required whether or not a WTR launch capability is provided.

5) Tug transportation between ETR and WTR will be by air.

6) Schedules are based on 2 shifts per day, 5 days per week at ETR, and 1 shift per day, 5 days per week at WTR.

7) Turnaround time from touchdown to liftoff is based on 160 working hours at ETR.

8) Kick stage costs are $0.93M for each launch.

9) Spacecraft costs are as follows (Reference 2):

	New	Refurbished
EO-12	$22M	$6.0M
EO-56	$23M	$5.7M

10) Spacecraft not retrieved (no WTR launch capability) are replaced with new spacecraft. Spacecraft retrieved (with WTR launch capability) are refurbished.

3.0 SUMMARY OF RESULTS

The cost to acquire and support launch operations at WTR for 8 years (1984-1991) is approximately $14.6M of which $2.7M is non-recurring and $11.9M is recurring. This breaks down as follows:

GSE	$ 1.484M
Facilities	1.991
Crew	10.752
Transportation	0.352
	$14.579M

If WTR launch capability is not provided, the cost penalty to launch out of ETR is approximately $109M. This breaks down as follows:

Kick Stages (7)	$ 6.5M
Spacecraft Replacement	
EO-12 (1)	16.0
EO-56 (5)	86.5
Total Cost Impact	$109.0M

The spacecraft replacement costs are incurred by replacing the spacecraft that would have been retrieved from WTR and refurbished with new spacecraft.

The cost of acquiring and supporting a launch capability at WTR ($14.6M) is relatively small compared to the mission impact ($109.0M) if this capability is not provided. In addition, the investment cost ($2.7M) is a relatively small portion of the WTR cost impact ($14.6M).

4.0 DISCUSSION

4.1 WTR OPERATIONS OVERVIEW

Figure 7-1 depicts overall operations at WTR involving the Orbiter with its Tug payload after returning from a mission. The Orbiter is moved from the landing strip to the Safing and Demating Facility (SDF) where any residual propellants are removed from the Tug and the tanks purged. The Orbiter with its Tug payload is then moved to the Orbiter Maintenance and Checkout Facility (OMCF) where the Tug is removed from the Orbiter cargo bay, safed, and flown to the Tug Maintenance and Checkout Facility (TMCF) at ETR for recycle. Since WTR is assumed to be an alternative landing site for ETR launches, these facilities and GSE must be provided whether or not a launch capability is provided at WTR.

Figure 7-2 presents an overview of the Shuttle launch facilities at WTR. Payloads are prepared for launch in the Payload Preparation Room (PPR) and transported to the launch pad in the Payload Changeout Room (PCR). The Mobile Service Tower (MST) provides general access to the Shuttle on the launch mount and the Access Tower provides access for final checkout and servicing through umbilicals.

Figure 7-3 shows more specifically the Tug operations in the launch area. The Tug is flown to WTR from the TMCF at ETR and transported from the landing strip to the PRR airlock by prime mover. The prime mover is removed and the Tug cleaned and moved into the PPR. The Tug is moved to the vertical position and a Systems Health Evaluation (SHE) test conducted. The spacecraft is mated to the Tug, an integrated test performed, and the total payload lifted into the PCR. The PCR is translated to the launch pad where the Tug is installed in the Orbiter cargo bay. Propellants and pressurants are loaded and final countdown commenced. These operations will require additional Tug GSE (identical to that used at ETR), facilities, and some Tug GSE peculiar to WTR.

4.2 COST IMPACT OF WTR LAUNCHES

4.2.1 GSE

The functional flow diagrams (Section III,A, Vol II, Final Report) and the functional description sheets (Appendix A, Final Report) were used to determine the additional GSE required for WTR. GSE required for abort was excluded since WTR is assumed to be an alternative landing site for ETR launches. (See 2.0 Assumptions and Ground Rules.)

The additional GSE identified and cost estimates are shown in Table 7-2. Descriptions may be found in Appendix B, Final Report. Figure 7-4 shows the locations of the GSE in the Payload Preparation

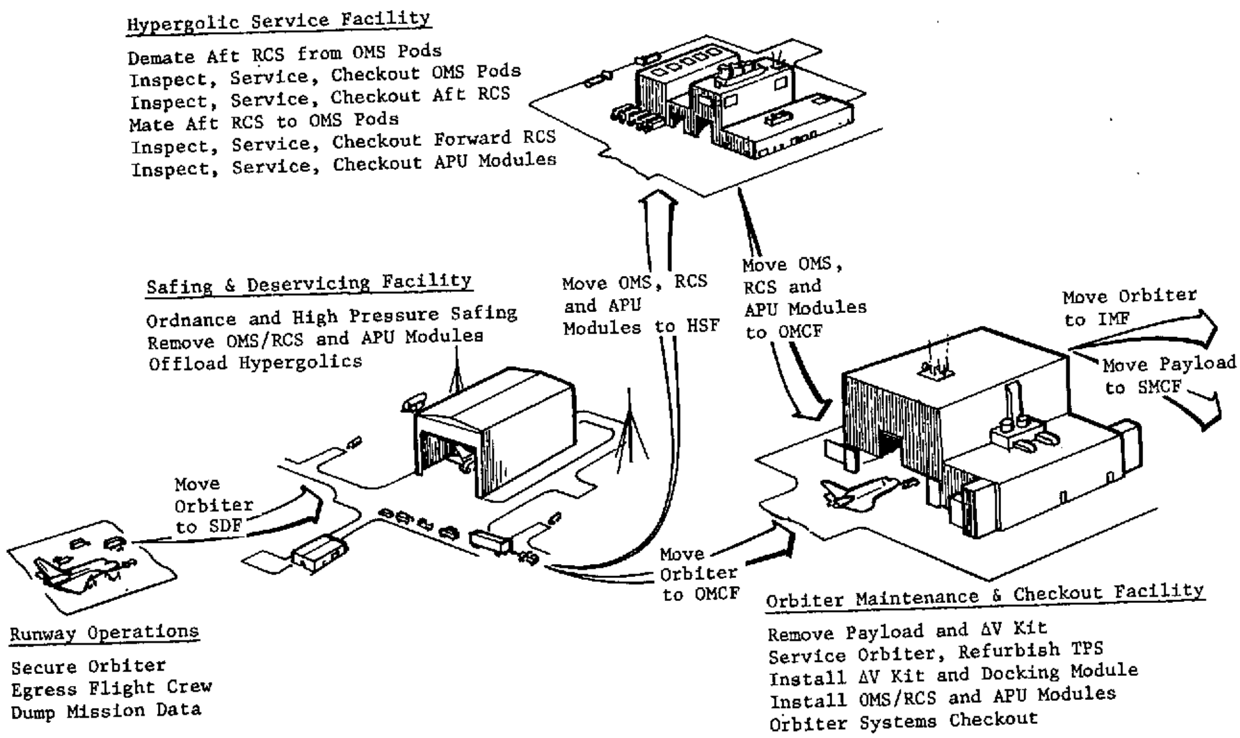


Figure 7-1 WTR Orbiter Processing

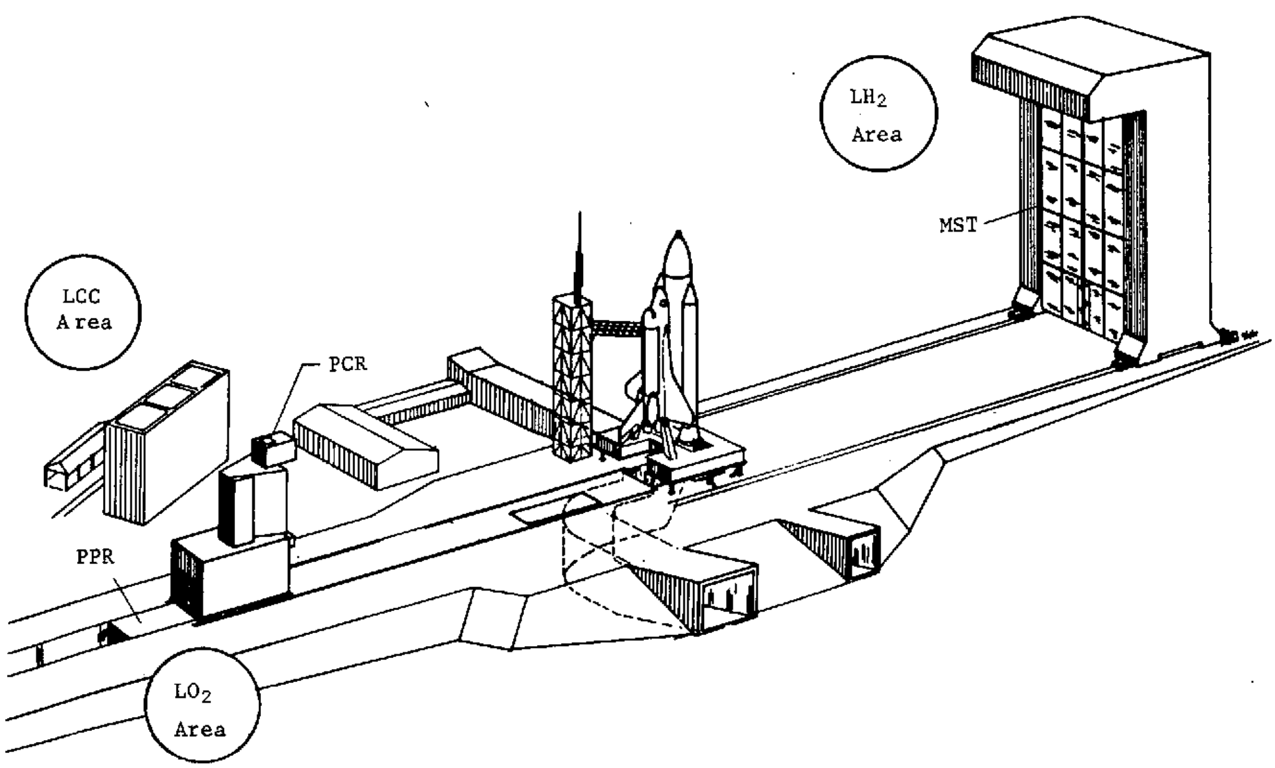
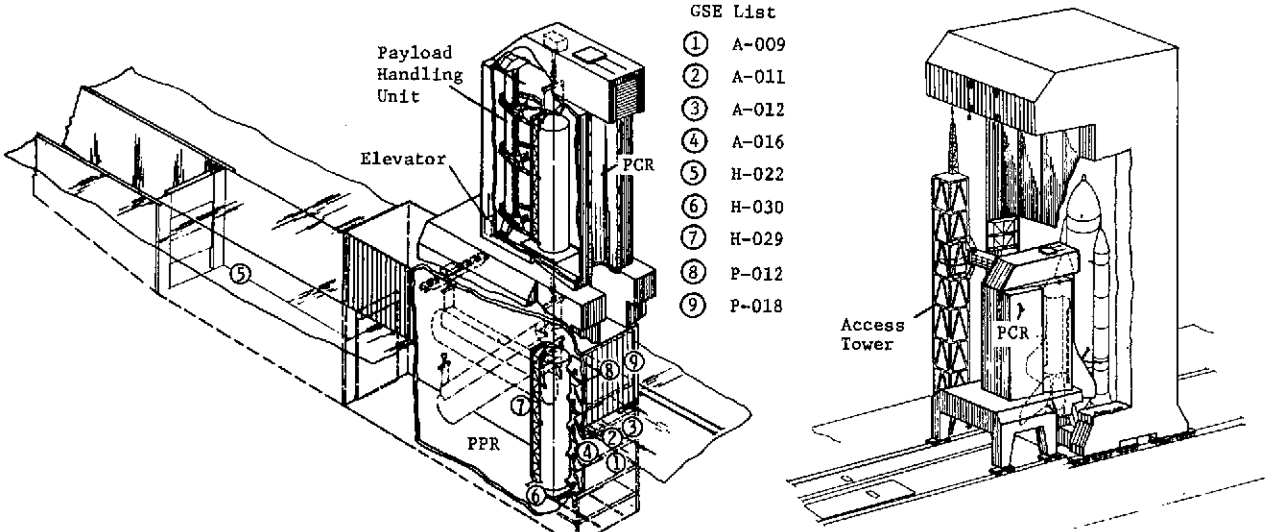


Figure 7-2 Launch Pad (SLC-6)



Payload Erection in PPR/PCR

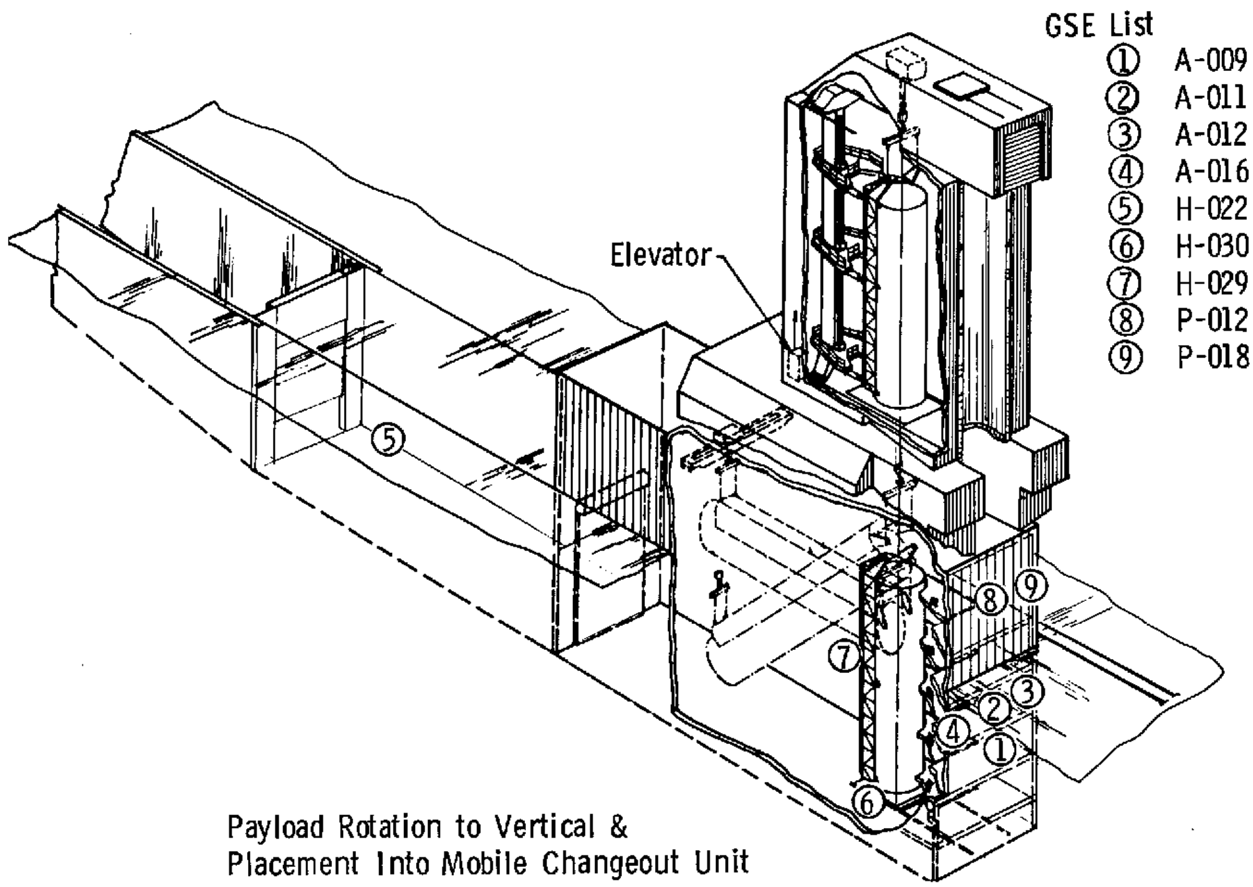
Payload Installation at Pad

Figure 7-3 Payload Erection and Installation

Table 7-2 GSE Requirements

	Non-recurring	Recurring
① A-009 Memory Load and Verify	$120.0 K	--
② A-011 Orbiter Cable Simulator	27.0	--
③ A-012 Umbilical Simulator	36.0	--
④ A-016 Ordnance Event Verification Cables	22.0	--
⑤ H-022 Air Carry Tiedown Kit	21.0	--
⑥ H-030 Vertical Adapter	42.5 + 40.0 Design	--
⑦ H-029 Vertical Workstand	8.0	--
⑧ P-012 APS Propellant Supply and Transfer Unit	44.5	--
⑨ P-018 Vacuum Pump and Gauge - APS	34.5	--
WTR Activation & Engineering of GSE Integration	144.0	--
Documentation (GSE & Facilities)	144.0	--
System Maintenance (GSE & Facilities) (8 Yrs)	--	800.0
Total	$ 684.0 K	$ 800.0 K

Room (PPR) at WTR. These are additional quantities of the same GSE used at ETR with the exception of the H-029 Vertical Adapter that is peculiar to WTR.



Payload Rotation to Vertical & Placement Into Mobile Changeout Unit

Figure 7-4 Location of GSE

4.2.2 Facilities

Additional facilities at WTR consist of those required for loading and unloading of propellants and pressurants at the launch pad. These services are obtained by tapping into the existing Space Shuttle facilities at the valve farm and include the lines, fittings, valves, umbilicals, connectors, and controls to route propellants and pressurants between the Tug and the Space Shuttle facilities. A fluid control and display console is also required in the LCC with associate electronics, cabling, and sensing devices.

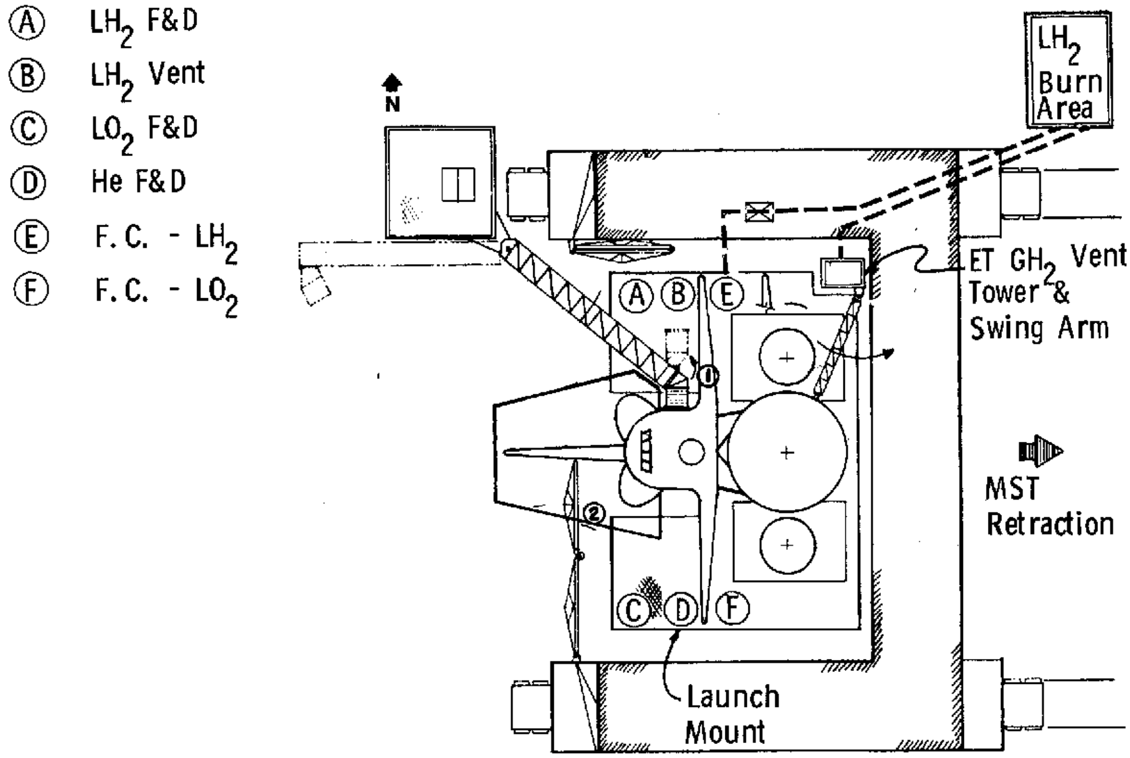


Figure 7-5 Location of Facility Modifications - Plan View

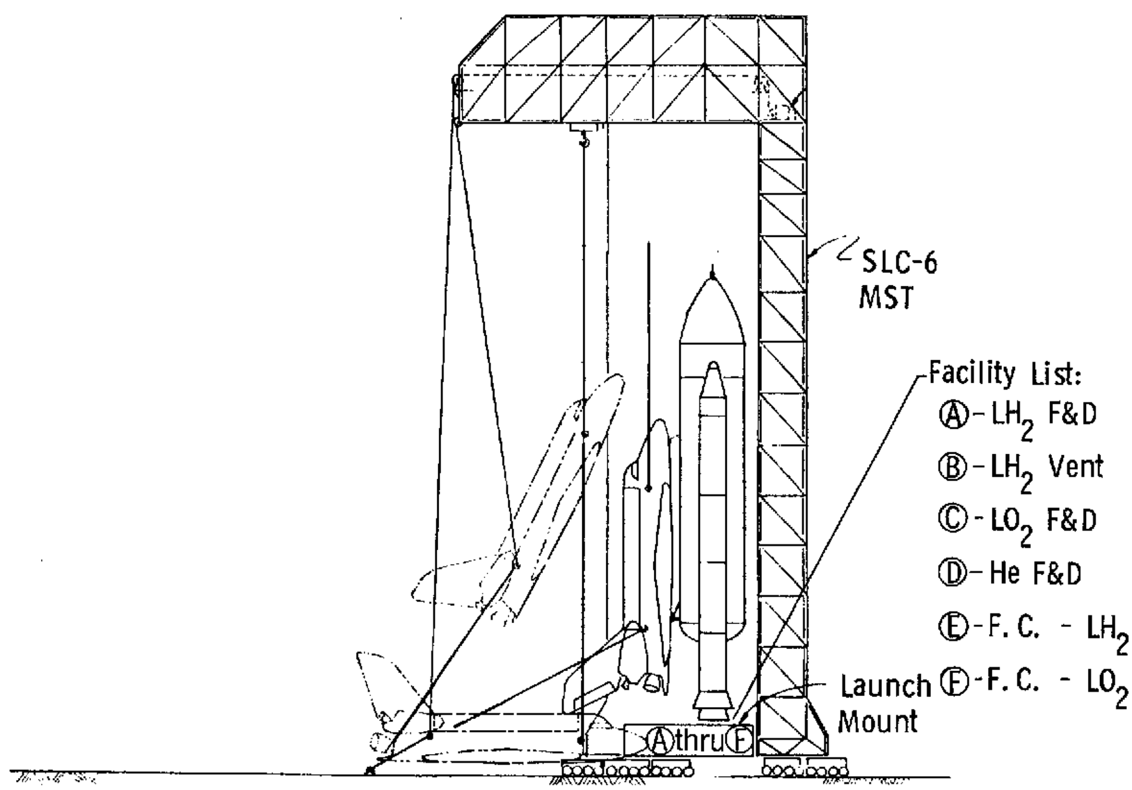


Figure 7-6 Location of Facility Modifications - Elevation View

Table 7-3 lists the facility systems required at WTR for the Tug and estimated costs. Locations are shown on Figures 7-5 and 7-6. Costs are based on modifications to existing facilities rather than design changes before construction start. Material costs could vary considerably depending on the type of production used. We assumed materials were obtained as add-on to Shuttle material costs; however, allowances were made for differneces.

Table 7-3
Facility Requirements

A	Liquid Hydrogen Fill and Drain System	$ 86 K
B	Liquid Hydrogen Vent System	62
C	Liquid Oxygen Fill and Drain System	113
D	Helium Fill and Drain System	29
E	Fuel Cell Servicing	
	Liquid Hydrogen	62
	Liquid Oxygen	62
F	Fluid Control and Display Console in LCC	337
	Installation/Verification	240
	Facility Design	1000
	Total	$1991 K

4.2.3 Crew Size

Estimates of crew size were based on supplementing the ETR crew sufficiently to support WTR launch operations without impacting ETR operations. The WTR launch operations crew would accompany the Tug from ETR to WTR and back. A small crew of supervisory personnel would be permanently stationed at WTR to interface between the transient crew from ETR and WTR operations.

Figure 7-7 shows a timeline for ETR and WTR launch operations with the manpower requirements for ETR and WTR superimposed. One launch can be achieved every two weeks whether or not WTR is used. However, when a launch is required from WTR, simultaneous operations occur on the ETR Tug and the WTR Tug. This increases the total manpower requirements as shown. Although the launch operations and support personnel accompanying the Tug to WTR amount to 34, the net increase in the ETR crew size is 21.* The skills required and the resulting costs are as follows:

Permanent WTR Launch Site Operations Crew (7)	$ 336 K/Year
WTR Tug Verification Manager	
Secretary	
Facility Support Supervisor	
Test Engineering Supervisor	
Quality Control Supervisor	
Test Operations Supervisor	
Safety Supervisor	
Delta to ETR Crew to Support WTR Launches (21)	$1,008 K/Year
GSE Engineer (1)	
GSE Techs (2)	
Avionics Engineers (2)	
Propulsion Engineers (2)	
Structures/Mechanical/Thermal Engineers (2)	
Configuration Control Engineer (1)	
Programmer/Software Engineer (1)	
Inspectors (2)	
Test Conductor (1)	
Technicians (6)	
Safety Engineer (1)	

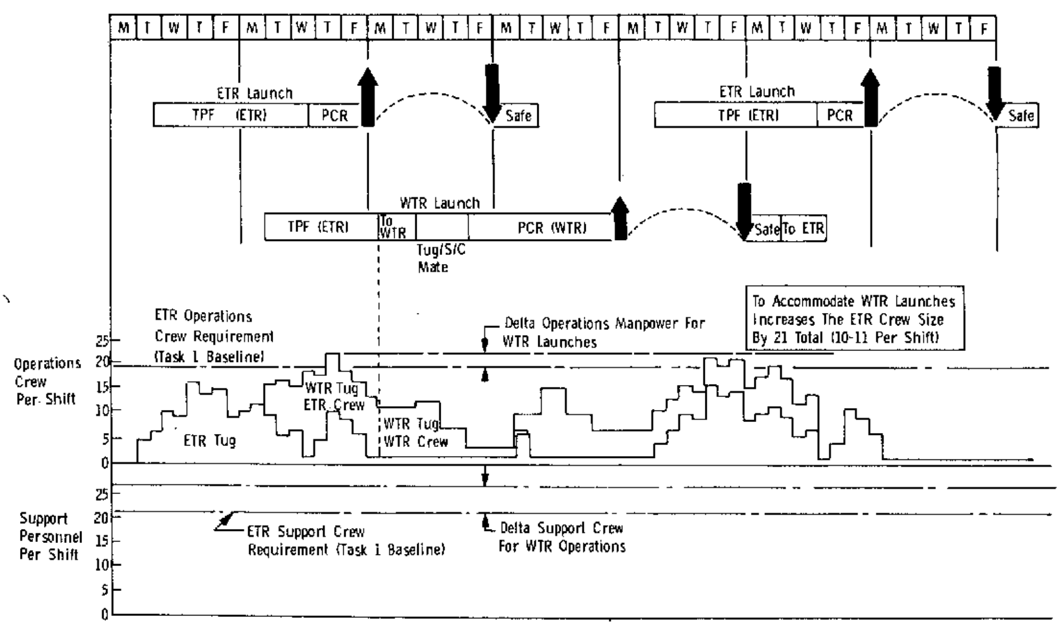


Figure 7-7 ETR and WTR Operations - Effect on Crew Size

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*The ETR crew size increase to 21 persons is totally charged to WTR even though the crew will be used at ETR for ETR support between WTR launches.

4.2.4 Fleet Size

It can be seen (Fig. 7-7) that the launch rate of one Tug every two weeks can be accomplished with two Tugs whether or not WTR is used. In reality, three would probably be required to allow for contingencies; however, the use of WTR does not impact the fleet size.

4.3 COST IMPACT WITHOUT WTR LAUNCH CAPABILITY

4.3.1 Mission Accomplishment

Spacecraft launched from WTR can also be launched from ETR; however, kick stages are required for EO-12 and EO-56. In addition, EO-12 and EO-56 cannot be retrieved from ETR because of range safety limitations (Ref 2). The spacecraft retrieved from WTR can be refurbished, but they must be replaced with new spacecraft if this capability is not provided.

Table 7-4 compares the mission accomplishment with and without WTR launch capability. AP-10 is not affected in either case. EO-12 has one launch and one retrieval between 1984 and 1991 with WTR capability. The retrieved spacecraft is refurbished. If launched from ETR, one kick stage is required and the one spacecraft that would have been retrieved from WTR is replaced with a new one. Similarly, EO-56 has a total of six launches from WTR, and five retrievals and refurbishments. If ETR is used, six kick stages are required and the five spacecraft that would have been retrieved at WTR are replaced with new ones.

4.3.2 Delta Mission Costs

Using the cost data presented in Section 2.0, the cost of refurbishing the spacecraft retrieved from WTR is as follows:

Spacecraft	Unit Cost to Refurbish, $M	Quantity	Refurbish Cost, $M
EO-12	6.0	1	6.0
EO-56	5.7	5	28.5
		Total	34.5

If WTR launch capability is not provided, the cost of the kick stages required to launch out of ETR is as follows:

Spacecraft	Unit Cost Kick Stage, $M	Quantity	Kick Stage Cost, $M
EO-12	0.93	1	0.9
EO-56	0.93	6	5.6
		Total	6.5

Table 7-4 Mission Accomplishments

WTR

Baseline WTR Payloads		ID	84	85	86	87	88	89	90	91	Total	Delta Relative To ETR
Explorer Upper Atmosphere	D/R	AP-01		1/	/1			1/	/1		2/2	None
TIROS	D/R	EO-12	/1			1/					1/1	Refurbish Spacecraft
Environmental Monitoring	D/R	EO-56	/1	1/	1/	1/1	1/1	/1	1/1	1/	6/	Refurbish Spacecraft
Tug Flights			2	1	1	1	1	1	2	1	10	None

ETR

Baselined WTR Payloads		ID	84	85	86	87	88	89	90	91	Total	Delta Relative To WTR
Explorer Upper Atmosphere	D/R	AP-01		1/	/1			1/	/1		2/2	None
TIROS	D/R	EO-12				1/					1/0	Replace 1 Spacecraft, Add 1 Kick Stage
Environmental Monitoring	D/R	EO-56		1/	1/	1/	1/		1/	1/	6/0	Replace 5 Spacecraft, Add 6 Kick Stage
Tug Flights			–	2	1	2	1	1	1	1	9	None

The cost to replace the unretrievable spacecraft with new spacecraft is:

Spacecraft	Unit Cost to Replace, $M	Quantity	Replacement Cost, $M
EO-12	22	1	22
EO-56	23	5	115
		Total	137

The delta mission costs include the cost of the kick stages plus the difference between new spacecraft and refurbished spacecraft:

Delta Mission Cost = $6.5M + ($137M - $34.5M) = $109.0M

Therefore, the impact of no WTR launch capability on the mission costs is approximately $109M.

4.4 COST COMPARISON

The cost to acquire and support WTR launch operations for 8 years is approximately $14.6M as compared to $109.0M if this capability is not provided. In addition, only $2.7M of the $14.6M is non-recurring or "front-end" cost.

5.0 CONCLUSIONS AND RECOMMENDATIONS

1) The total cost to acquire and support WTR launch operations ($14.6M) is relatively small compared to the mission impact ($109M) if the capability is not provided.

2) The investment cost ($2.7M) is only a small portion of the total WTR cost ($14.6M).

3) Tug launch capability, as defined herein, should be included in the WTR baseline.

6.0 REFERENCES

1) First Data Exchange Package - Tug Fleet and Ground Operations Schedules and Controls, September 1974 (Martin Marietta Corporation).

2) IUS/Tug Payload Requirements Compatibility Study, First Progress Review and Data Exchange, NASA/MSFC Contract NAS8-31013 (McDonnell Douglas Astronautics Corporation).

MCR-74-488
NAS8-31011

Addendum 8 January 1975

SENSITIVITY ANALYSIS

Prepared by

Q. L. Eberhardt
Systems Engineering

Addendum 8
Sensitivity Analysis

CONTENTS

Table

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1.0 INTRODUCTION AND CONCLUSIONS

The plans for task 3.0 and task 9.0 of this study require analysis to indicate the sensitivity of (1) mission and traffic model changes, (2) uneven launch centers, (3) Tug turnaround time, (4) launch rate, etc. All of the sensitivity factors affect resource requirements, such as GSE, facilities, manpower, and number of Tugs. This analysis determines the sensitivity of the resource requirements to the variation of the abovementioned factors to fulfill the requirements of tasks 3.0 and 9.0 of the study plan. As an add-on a modular Tug concept sensitivity has been included.

The conclusions of this analysis follow:

1) The number of Tugs required is extremely sensitive to the number of expendable flights and the number of flights per expended Tug. To optimize the fleet size, the expendable flights should be minimized and the flights per expended Tug maximized.

2) The number of Tugs required is very sensitive to Tug life in the 10- to 20-mission region and not very sensitive in the 20- to 30-mission region, indicating that expenditures of time and money to extend life beyond 20 missions is not warranted with the present traffic model, primarily because of expendable missions.

3) The number of Tugs required is generally insensitive to dedicating Tugs as NASA or DOD.

4) Extending IUS beyond 1983, in general, will not reduce the number of Tugs required, based on a given traffic model.

5) Reusable IUS life and quantity requirements are extremely sensitive to the expendable flights and flights per expended reusable IUS. To optimize quantity requirements and minimize life requirements, the number of expendable flights should be minimized and flights per expended reusable IUS maximized.

6) A 20-mission IUS is not warranted with the present mission model, unless it costs little or no more than a 15-mission IUS.

7) The number of reusable IUSs required is generally insensitive to dedicated NASA or DOD use.

8) The WTR crew provision should be included in the manpower planning to accommodate high launch rates, uneven launch rates, uneven mission durations and other contingencies, although routinely the ETR crew provision is sufficient.

9) NASA and DOD dedicated crews impose a high increase (30 to 50%) in operations crews, and such dedication is not generally recommended.

10) Because of the high number of expendable Tug flights, the modularized Tug concept is probably not warranted.

11) Nominally one set of resources (men, facilities, GSE) will satisfy the traffic model.

12) A basic program decision regarding expendability and reusability of IUS needs to be made.

13) "Block" build of Tugs does not affect fleet size.

2.0 GUIDELINES, GROUND RULES AND ASSUMPTIONS

The guidelines, ground rules, and assumptions used in the sensitivity analysis follow.

1) Traffic model baseline is presented in Table 8-1.

2) Tug life baseline is the requirement of MSFC for the 1973 Tug systems studies of 20 flights per Tug.

3) Baseline ground turnaround time for Tug is 160 hours in accordance with the flow chart of subplan A.

4) NASA vs DOD traffic model is shown in Table 8-2.

5) The reusable IUS life baseline is 20 flights per IUS.

6) Number of expendable flights of reusable IUSs and Tugs is shown in Table 8-3.

Table 8-1 Traffic Model, Number of Flights

	Configuration / Year	1980*	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	Total
IUS	Expendable IUS, No Transition	9	16	14	17									56
	Expendable IUS, 1-yr Transition	9	16	14	17	7								63
	Expendable IUS, Residual Flights through 1991	9	16	14	17	7	4	3	1	1	2	1	1	76
	Reusable IUS, No Transition†	10	20	14	16									60
	Reusable IUS, 1-yr Transition†	10	20	14	16	8								68
	Reusable IUS, Residual† Flights through 1991	10	20	14	16	8	5	4	2	2	2	2	2	87
Tug	Tug No Transition					19	22	24	18	18	16	26	22	165
	Tug, with IUS Transition and Residuals					13	19	23	18	18	16	26	22	155

* 1980 Totals from Martin Marietta IUS Study Data (For SAMSO)
† Reusable IUS Totals from Martin Marietta Study Data (For SAMSO), 1984 through 1991 Data Derived

Table 8-2 NASA vs DOD Traffic Model

	Year / Agency	1984	1985	1986	1987	1988	1989	1990	1991	Total
Tug	NASA	15	12	17	13	12	12	19	15	115
	DOD	4	10	7	5	6	4	7	7	50
Reusable IUS*	(1980-83) NASA (42)	5	3	3	2	1	2	1	2	61
	DOD (18)	3	2	1		1		1		26

*Extrapolated - 22/76 of All Reusable IUS Flights Are DOD in 1980 to 1983 per Martin Marietta IUS Study for SAMSO (1975)

Table 8-3 Reusable IUS and Tug, Number of Expendable Flights

Year / Vehicle	80	81	82	83	84	85	86	87	88	89	90	91	Total
Reusable IUS	2	7	2	3	2	2	1	1		1		1	22
Tug						4	2				1	1	8

IUS Stop for No Transition (after 83)

IUS Stop for 1-yr Transition (after 84)

Tug Data - MDAC, No. MDC G 5452, September 1974

IUS Data - 1980-1983, Martin Marietta for SAMSO Study for Storable IUS
1984-1991, Martin Marietta Derived, 25% of All Flights are Expended

3.0 SUMMARY OF RESULTS

3.1 TOTAL TUG REQUIREMENTS

1) The baseline requirements vary between a total of 13 and 16 Tugs. The final number is dependent on number of flights per expended Tug.

2) Requirements are insensitive to build/delivery rate as long as active fleet size and inventory requirements are met.

3) Tug requirements are very sensitive to:

   a) Total number of Tug flights

   b) Total number of expendable Tug flights

c) Total number of flights by each expended Tug

d) Maximum flights per Tug

4) Tug requirements are not too sensitive to IUS transition and continued use, varying only by one over the probable zone of flights per expended Tug (Fig. 8-8).

5) Tug requirements are generally not sensitive to dedicated NASA and DOD use, varying only by a maximum of one over the probable zone of flights per expended Tug (Fig. 8-7).

3.2 ACTIVE FLEET SIZE REQUIREMENTS - TUG

1) Two active Tugs are required generally, based on launch rate.

2) Dedicated Tugs (NASA and DOD) would increase the active fleet size to three.

3) Downstream refinement of the launch schedule may impose additional requirements on the active fleet (high launch rate per month greater than monthly average of annual launch rate).

4) Expending Tugs increases the active fleet size to a minimum annual inventory of four in 1984, six in 1985, four in 1990, and three in 1991.

3.3 TOTAL IUS REQUIREMENTS

1) Expendable requirements vary from 56 to 76 and reusable requirements from 15 to 27, depending on transition with Tug.

2) A 20-flight life IUS is probably not warranted and a 5-flight life IUS may be sufficient (with four flights per expended reusable IUS).

3) IUS requirements are generally not sensitive to NASA and DOD dedication.

3.4 ACTIVE FLEET SIZE REQUIREMENTS (REUSABLE IUS)

Active fleet size requirements (reusable IUS) are depicted in Table 8-4.

3.5 MANPOWER SENSITIVITY SUMMARY

1) Manpower sensitivity to traffic model launch rate - none.

2) Manpower sensitivity to WTR launches - increase operations crew requirement by about 30%.

Table 8-4 Reusable IUS Annual Inventory Requirements

Item / Year	80	81	82	83	84	85	86	87	88	89	90	91
Launch Rate IUSs	1	2	1	1	1	1	1	1	1	1	1	1
Expended IUSs	2	7	2	3	2	2	1	1		1		1
*DOD Dedicated IUS	1	1	1	1	1	1	1		1		1	
*Total Annual Inventory	4	10	4	5	4	4	3	2	2	2	2	2
*Subtract One from Total If IUSs Not Dedicated												

3) Sensitivity to uneven launch centers and mission duration - none.

4) Sensitivity to work day/week - occasional day/week overtime to accommodate uneven launch centers or missions.

5) Sensitivity to NASA and DOD dedicated crews - increase operational crew requirements by approximately 50%.

3.6 FACILITY SENSITIVITY

Two each launch pads and TPF test cells are required to satisfy short-term launch rates.

3.7 GSE SENSITIVITY

GSE requirements are not generally sensitive to short-term launch rate. There are five exceptions, out of 70 items, requiring extra quantities because of high use rate.

3.8 MODULAR TUG CONCEPT

Because of the high number of expendable Tug flights in the program, the modular Tug concept is not particularly attractive.

4.0 DISCUSSION

4.1 TOTAL TUG REQUIREMENTS

The total number of Tugs required is determined by the formula of Figure 8-1. As can be seen from that formula the number of Tugs is sensitive to several factors: total number of flights, number of expendable flights, number of flights by Tugs being expended, maximum number of flights per Tug before it is "worn out", and unreliability losses. Figures 8-2, 8-3, and 8-4 depict the variation in Tug requirements as the formula factors vary.

$$\text{Total Tugs Required} = \text{Total Number of Expendable Flights} + \left[\frac{\text{Total Number of All Tug Flights} - \text{Total Number of Flights by Tugs Being Expended}}{\text{Maximum Number of Flights per Tug}}\right] + \text{Unreliability Losses}$$

$$= 8 + \left[\frac{165 - \text{(Varies from 56 to 105)}}{\text{Baseline of 20}}\right] + \begin{array}{l}\text{1 per 100 Flights}\\\text{(2 Total)}\end{array}$$

$$\doteq 8 + 3 + 2 \text{ To } 8 + 6 + 2$$

Baseline

$$\boxed{\text{Total Tugs Required} = \text{13 to 16 Depending on Expendable Flight Schedule}}$$

Figure 8-1 Total Number of Tugs Required - Entire Program

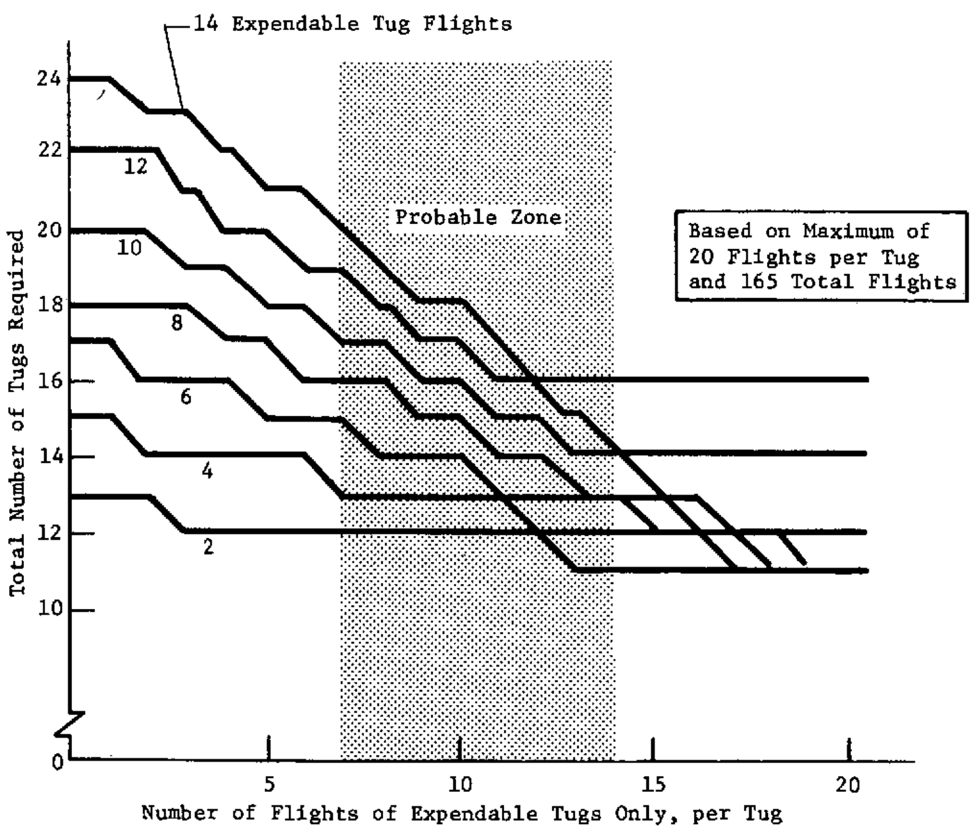

Figure 8-2 Sensitivity to Number of Expendable Flights and Flights/Expendable Tug

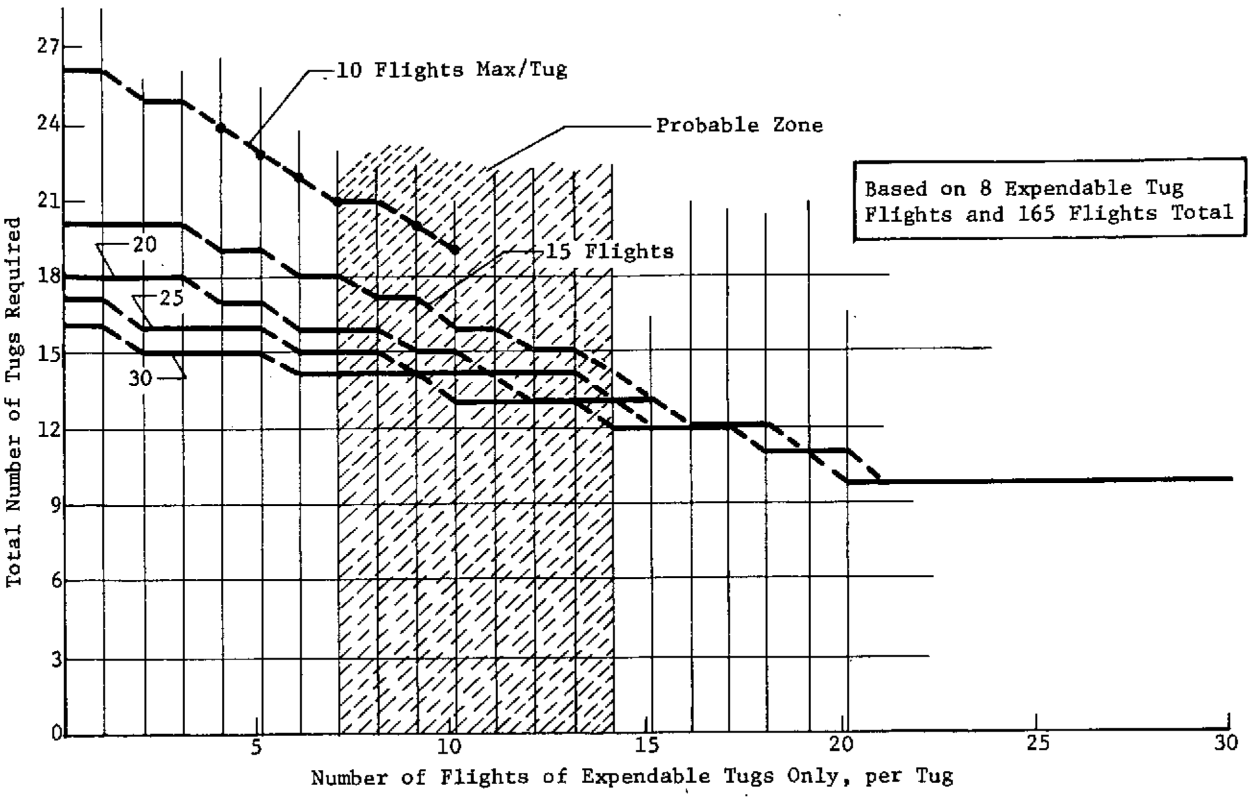

Figure 8-3 Sensitivity to Flights/Tug and Flights/Expendable Tug

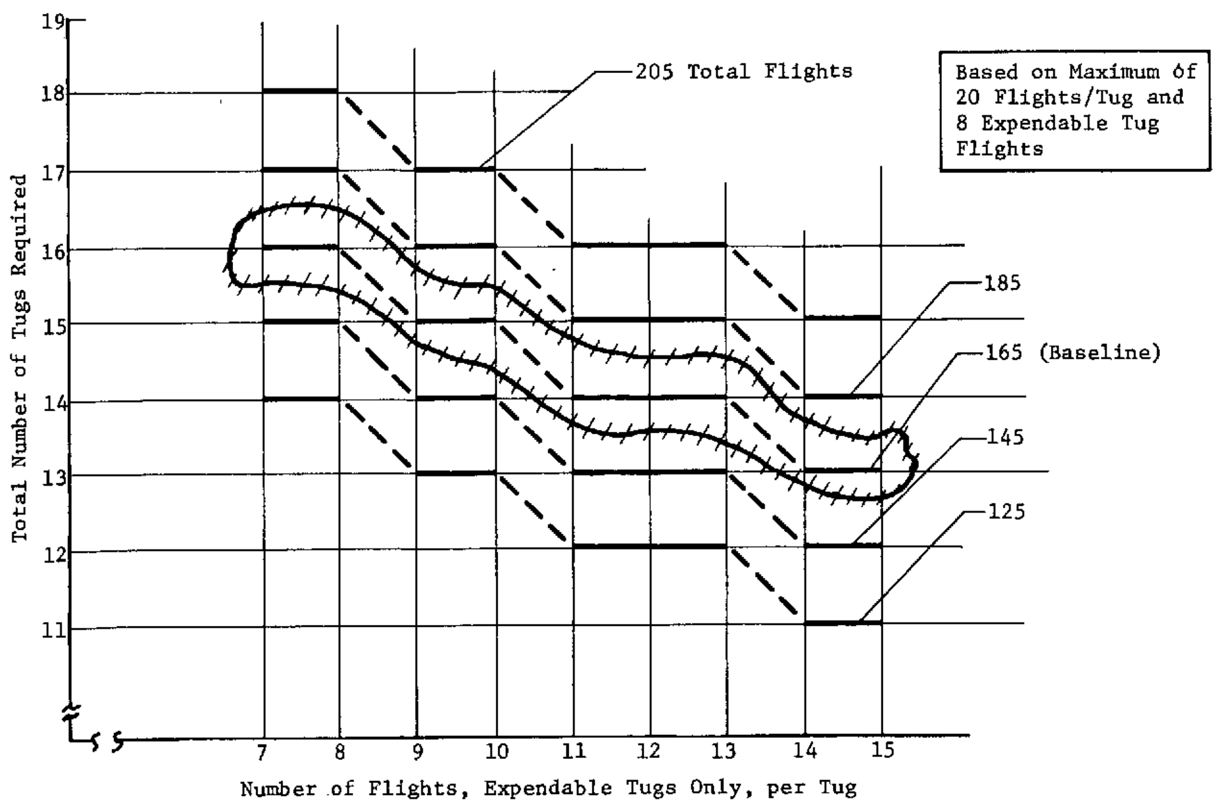

Figure 8-4 Sensitivity to Total Number of Tug Flights

Figure 8-2 indicates that the number of Tugs required is sensitive to the number of expendable Tug flights (from 11 to 24 as the number of expendable flights goes from 2 to 14). Even in the probable zone of seven to 14 flights per Tug before it is expended, the total number of Tugs varies from 11 to 20. Therefore, to optimize the total number of Tugs required, (1) minimize the number of expendable Tug flights, (2) maximize the number of flights each Tug gets before it is expended.

Figure 8-3 indicates the sensitivity of the number of Tugs required to the maximum number of flights per Tug using the baseline traffic model. The figure depicts large sensitivity between 10 and 20 flights maximum per Tug, and less sensitivity between 20 and 30. For example, in the probable zone of flights per expended Tug, the number of Tugs required increases by five in the 20 to 10 flights maximum per Tug region, and the number of Tugs required only decreases by two maximum (usually one) in going from 20 to 30 maximum flights per Tug. Therefore, with the present traffic model, the 20-flight maximum per Tug from the MSFC studies of 1973 appears to be optimum from point of view of the number of Tugs required.

Figure 8-4 indicates the sensitivity of the Tug requirements to increases and decreases in the total number of Tug flights, indicating a sensitivity of one Tug for every 20-flight change, which is what would be expected with 20 flights maximum per Tug. If the traffic model increases significantly, more than 20 flights maximum per Tug may be warranted to keep the Tug requirements down. Reduction of the number of flights in the model does not warrant an increase in the maximum number of flights, unless the number of expendable flights is reduced. To ascertain the merit of providing a longer life Tug would require a separate tradeoff study.

Tug requirements are insensitive to build rate and delivery rate as long as active fleet size and expend requirements are met. Figures 8-5 and 8-6 both show the same number of Tugs required overall. This insensitivity allows for program flexibility to use a "block" concept over the Tug operational span without affecting the total number of Tugs in the fleet.

The sensitivity to dedicated DOD and NASA Tugs has been analyzed. Figure 8-7 depicts the sensitivity of dedicating vs nondedicating; the general observation is that the number of Tugs required is not very sensitive to dedication.

Finally, the Tug requirements are sensitive to the IUS transition as depicted by Figure 8-8 but generally only dependent on the number of flights per expended Tug. Given a low number of flights per expended Tug (7) will require one less Tug (16 vs 15); given a high number of flights per expended Tug (14) will result in no reduction in number of Tugs, IUS transition notwithstanding.

Tug No.	1984				1985				1986				1987				1988				1989				1990				1991				Flights per Tug
1	1	1	2	1	2																												7
2	1	2	1	1	2																												7
3	1	1	1	2	2																												7
4	1	1	1	1	2																												6
5					1	2	2	2	3																								10
6					2	2	2	1	3																								10
7										1	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1								19(20)
8										1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				20
9										1	1	1	1	1				1		1	1		1		2	1	1	1	1	1	2	2	20(18)
10										1	1	1	1		1				1			1		1		2	1	1	1	2	2	2	19(20)
11										1	1	1	1		1			1	1	1		1	1		2	1	2	1	1	1	1	1	20
12										1	1	1	1				1	1	1	1	1			1	1	2	2	1	1	1	1	1	20
Total Flights	19				22				24				18				18				16				26				22				165

Tug No. 13 } Lost
Tug No. 14 }

Total Tugs = 14

> Tug Requirements Are Not Dependent on Build Rate as Long as Active Fleet Size Requirements Are Met

Figure 8-5 Early Build and Delivery

Tug No.	1984				1985				1986				1987				1988				1989				1990				1991				Flights/ Tug
1	1	1	2	1	2																												7
2	1	2	1	1	2																												7
3	1	1	1	2	2																												7
4	1	1	1	1	2																												6
5					1	2	2	2	3																								10
6					2	2	2	1	3																								10
7										3	3	3	2	2	3	2	2																20
8										3	3	3	3	2	2	2	2																20
9																	2	2	1	2	2	2	2	2	3								18
10																	2	1	2	2	2	2	2	2	1	1	1	1	1				20
11																									1	3	2	3	2	3	3	3	20
12																									1	3	3	3	3	3	2	2	20
Total Flights	19				22				24				18				18				16				26				22				165

Tug No. 13 } Lost
Tug No. 14 }

Total Tugs = 14

> Tug Requirements Are Not Dependent on Build Rate as Long as Active Fleet Size Requirements Are Met

Figure 8-6 SLOW Build and Delivery for Block Concept

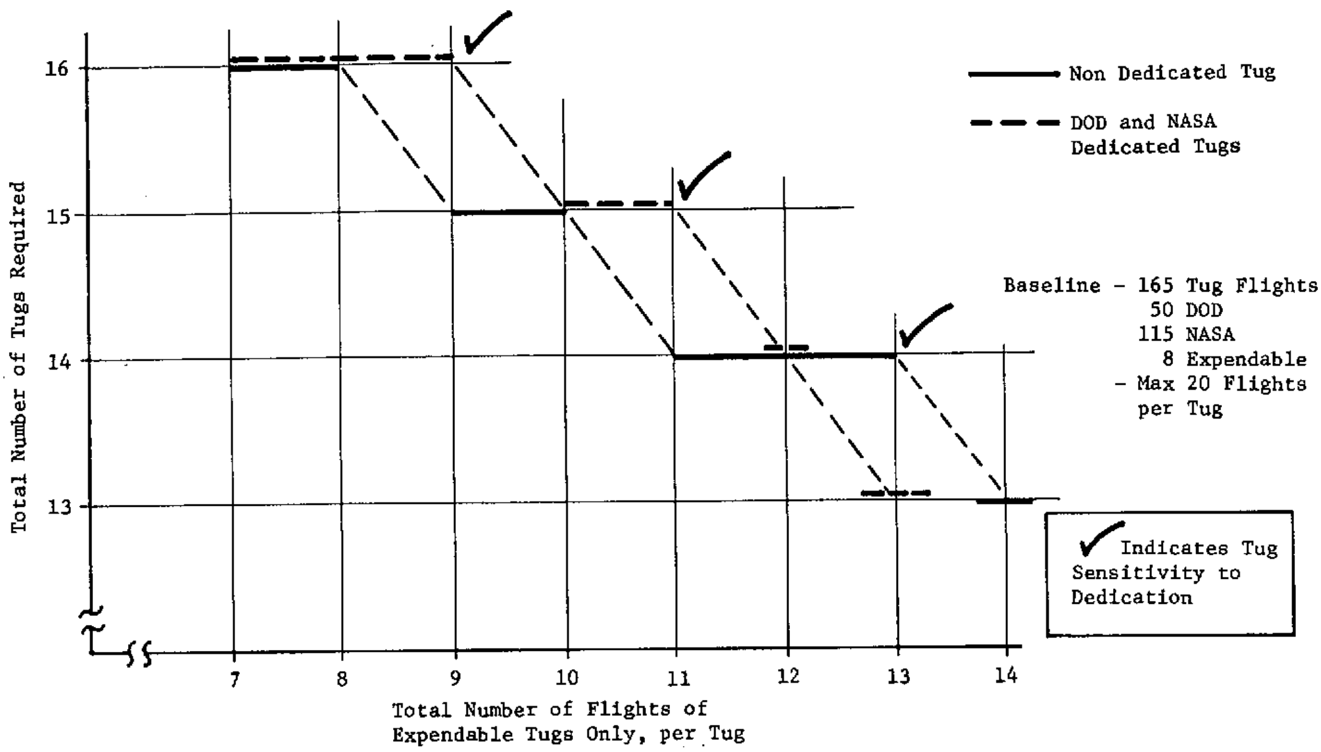

Figure 8-7 Sensitivity to NASA and DOD Dedicated Tugs

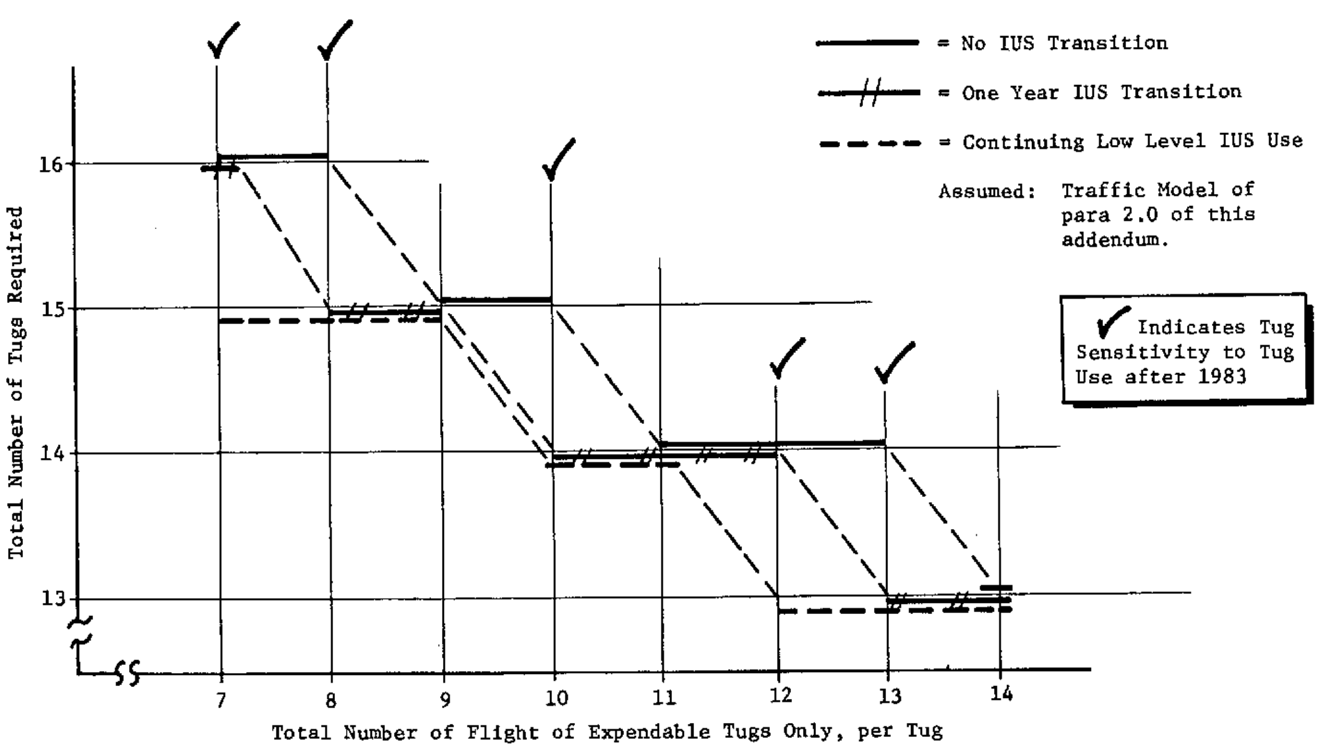

Figure 8-8 Sensitivity to IUS Transition and Continued Use

4.2 ACTIVE FLEET SIZE REQUIREMENTS(TUG)

The Tug active fleet size is sensitive to three factors: (1) the annual launch rate (for long term determination - 1 year), (2) working days between Tug launch centers (for short term determination - few weeks to few months), and (3) the time it takes to process a Tug from landing through liftoff, i.e., ground turnaround time. Figure 8-9 shows the sensitivity of the active fleet size to these three factors. The probable zone on the figure indicates a need for two Tugs in the active fleet; however, short-term demands in the launch rate could increase the requirement to four. A sizable increase in the ground turnaround time can be tolerated without increasing the active fleet size (160 to 240 hours), based on the annual launch rate. The converse is also true.

The active fleet size is sensitive to the expendable rate such that in a given year the number of Tugs required (inventory) is the active fleet required to meet the launch rate plus those that will be expended (Fig. 8-5 and 8-6 give the annual inventory requirement).

If Tugs were to be dedicated as NASA or DOD Tugs, the active fleet size requirement would be increased by one as indicated by Figure 8-10, based on the NASA and DOD launch rates indicated in Table 8-2.

4.3 TOTAL IUS REQUIREMENTS

The total number of IUSs required is dependent on a major program decision to provide expendable or reusable IUSs. If the decision is made to go expendable, the total IUS requirement is equal to the number of IUS flights (Ref Table 8-1). If the decision is made to go reusable, then the same general formula as used for Tug (Fig. 8-1) will be used to determine IUS quantity requirements. The number or reusable IUSs is further dependent on the IUS to Tug transition, and the requirements indicated reflect that dependence.

4.3.1 Total Reusable IUS Requirements, No Transition with Tug (1980-1983)

Figure 8-11 depicts the sensitivity of the reusable IUS requirements to the expendable flight schedule and indicates a total requirement of 15 to 18 IUSs.

4.3.2 Total Reusable IUS Requirements, One Year Transition with Tug (1980-1984)

Figure 8-11 depicts this sensitivity, and indicates a total requirement of 17 to 20 IUSs.

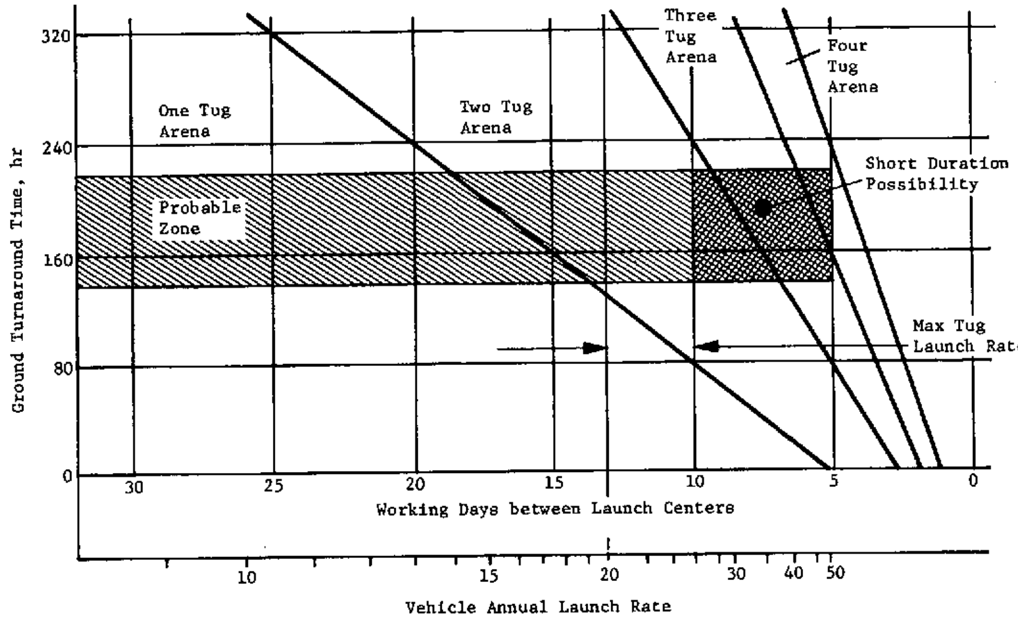

Figure 8-9
Vehicle Active Fleet Size - Tug or IUS - vs Turnaround Time, Launch Rate, Launch Centers

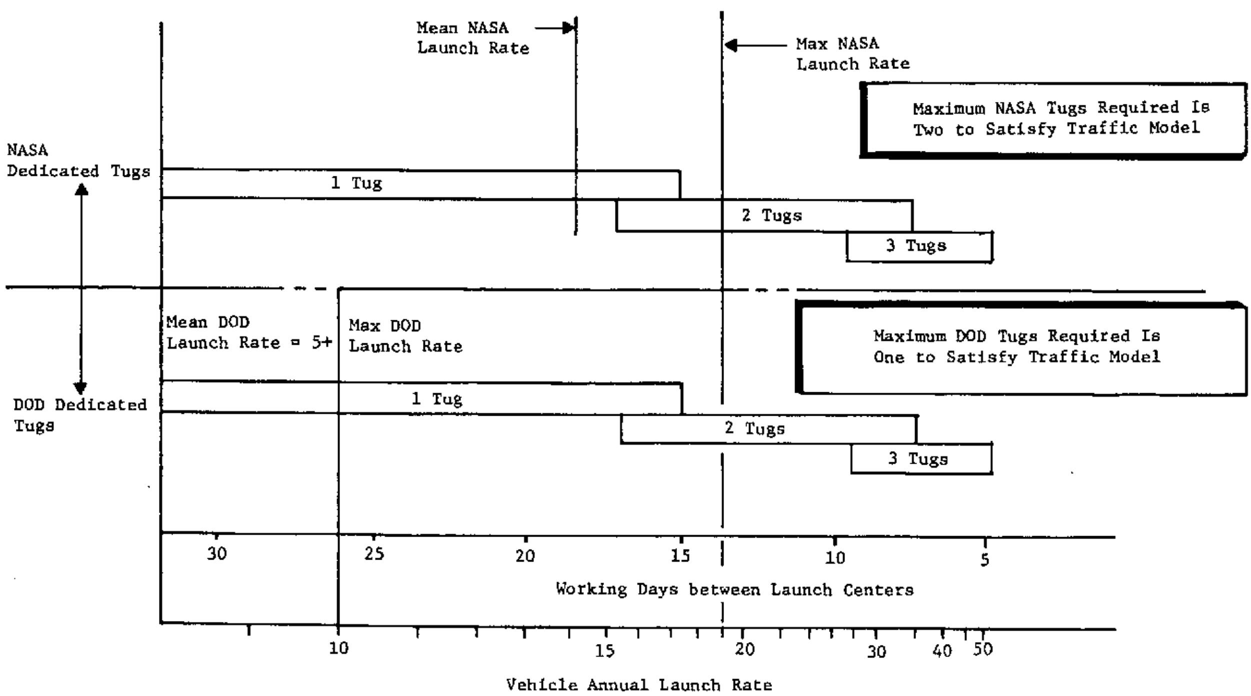

Figure 8-10 Minimum Active Fleet Size, NASA and DOD Dedicated Tugs

$$\text{Total Reusable IUSs Required} = \text{Total Number of Expendable IUS Flights} + \left[\frac{\text{Total Number of IUS Flights} - \text{Total Number of Flights by IUSs Being Expended}}{\text{Maximum Number of Flights per IUS}}\right] + \text{Unreliability Losses (1 per 100 Flights)}$$

For 1980-1983, Total $= 14 + \left[\frac{60 - (\text{Varies from 14 to 60})}{\text{Baseline of 20}}\right] + 1 = 15$ to 18

For 1980-1984, Total $= 16 + \left[\frac{68 - (\text{Varies from 16 to 68})}{\text{Baseline of 20}}\right] + 1 = 17$ to 20
(1-yr Transition)

For 1980-1991, Total $= 22 + \left[\frac{87 - (\text{Varies from 22 to 87})}{\text{Baseline of 20}}\right] + 1 = 23$ to 27
(Residual IUS throughout Program)

In all cases, higher total number represents one flight per expended reusable IUS, and lower number represents maximum flights per expended reusable IUS.

Figure 8-11 Total Number of Reusable IUSs Required

4.3.3 Total Reusable IUS Requirements, Residual IUS Use (1980 - 1991)

Figure 8-11 depicts the requirement of 23 to 27 IUSs.

4.3.4 Sensitivity

Like the Tug, the IUS requirements are sensitive to total number of flights, number of expendable flights, number of flights per expended reusable IUS, maximum number of flights before the IUS is "worn out", and unreliability losses. Figures 8-12 through 8-14 depict this sensitivity. The IUS is sensitive to the number of expendable flights with the number varying up or down approximately one as the expendable flights vary up or down by one. Figure 8-13 shows that with the present traffic model there is very little sensitivity between a 15-flight and 20-flight life IUS indicating that much expenditure for a 20-flight life reusable IUS may not be warranted. The figure depicts that a 5-flight life may be sufficient if each expended reusable IUS can get at least four flights. In all cases, the number of IUSs is very sensitive to the number of flights per expended IUS leading to the same IUS conclusion that was reached for Tug: To optimize total IUS requirements, maximize flights per expended IUS and minimize number of expendable flights.

Figure 8-14 indicates the sensitivity of IUS requirements to total number of flights. Comparing Figure 8-14 to Figure 8-4, it is noted that there are as many Tugs required for 155 total flights as for 165, and to increase reusable IUS flights from 60 (no transition) to 87 (residual IUS flights through 1991) increases the reusable IUS fleet size by a minimum of seven indicating that residual IUS flights through 1991 with the present traffic model (Tables 8-1 and 8-3) is not warranted. Note a further traffic model tradeoff is required to optimize the flights for IUS and Tug to ensure that the increase in IUS flights and decrease in Tug flights relationship is optimum.

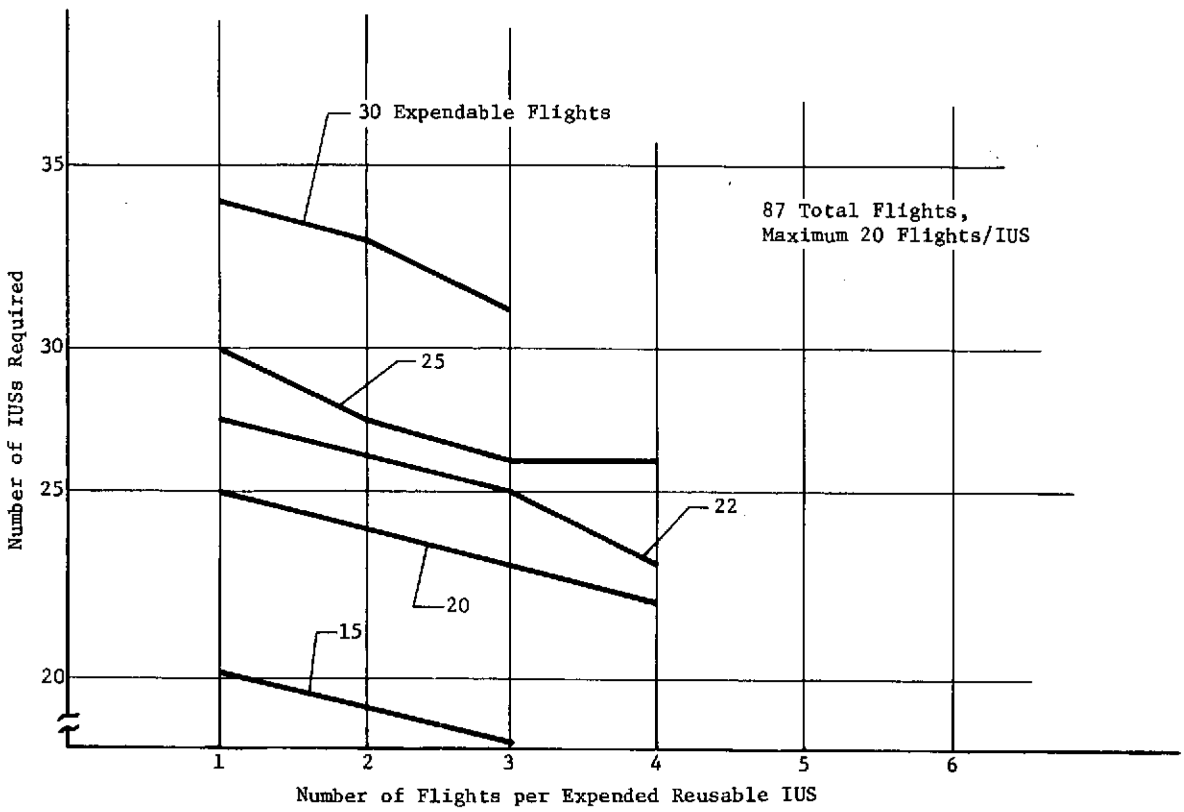

Figure 8-12 Reusable IUS Requirements, Sensitivity to Expendable Flights

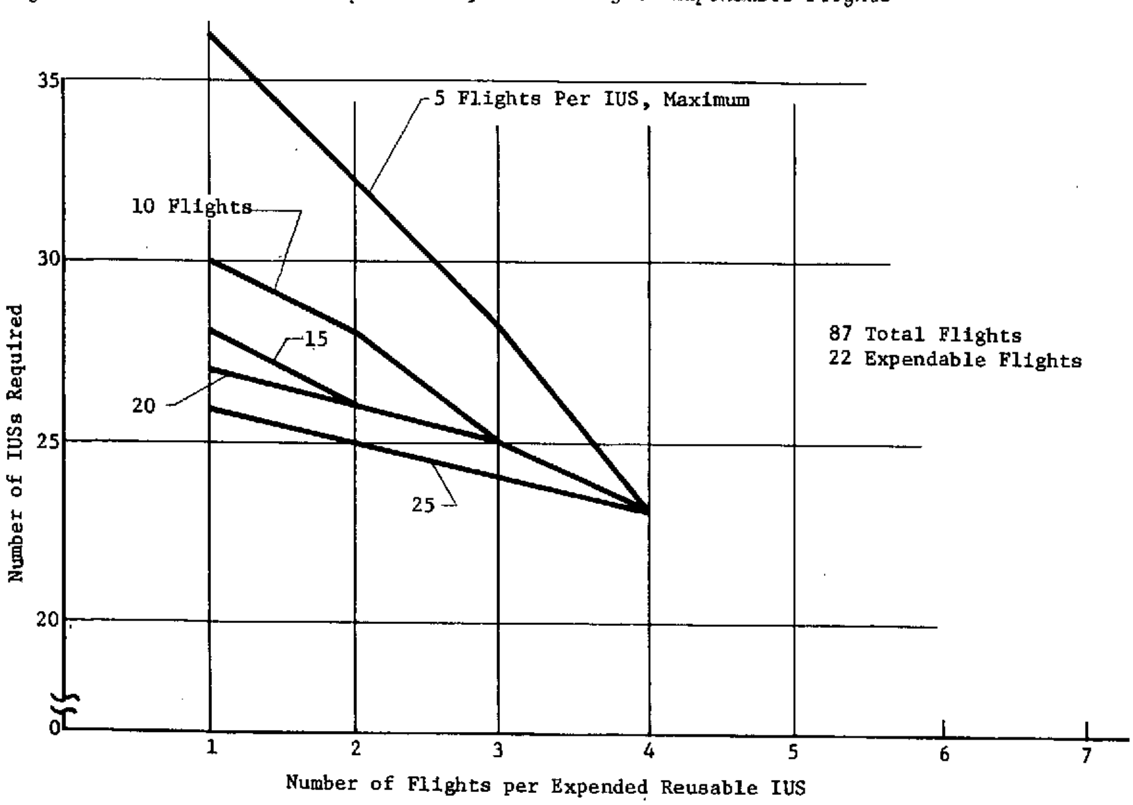

Figure 8-13 Reusable IUS Requirements, Sensitivity to Flights/IUS Maximum

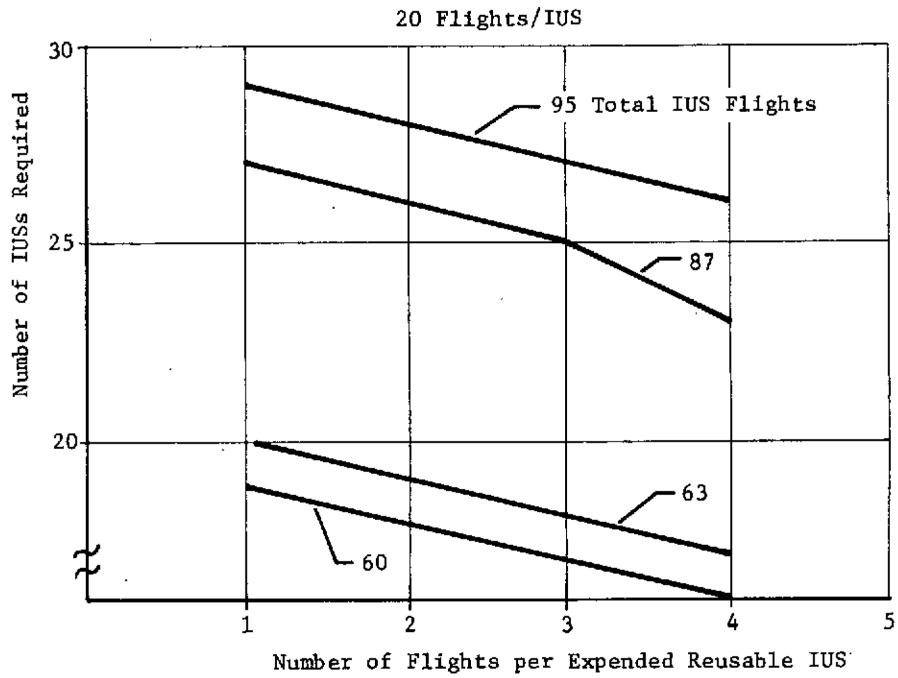

Figure 8-14
Reusable IUS Requirements, Sensitivity to Total Number of Flights

A final sensitivity has been studied, dedicated NASA and DOD reusable IUSs. Using the formula of Figure 8-11 for NASA and DOD flights (Ref 8-2) will result in a curve in Figure 8-15 showing that the quantity of IUSs is generally insensitive to dedicated use.

4.4 ACTIVE REUSABLE IUS REQUIREMENTS

The active fleet size reusable IUS requirements, like the Tug, are sensitive to turnaround time, annual launch rate and working days between launch centers. Figure 8-9 depicts IUS sensitivity as well as Tug sensitivity, indicating a probable need of only one active IUS based on launch rate (two in 1981). Again, the reusable IUS annual inventory is a function of the expending rate, so if one is added to each reusable IUS quantity shown in Table 8-3, the result is the annual inventory requirement. NASA and DOD dedicated reusable IUSs would increase this number by one more; Table 8-4 gives this result.

4.5 MANPOWER SENSITIVITY

In general support personnel requirements are not affected by launch rate, uneven launch centers, mission duration, WTR requirements, etc, but operations personnel are. Therefore, each of these factors has been studied to determine the sensitivity of operations personnel requirements.

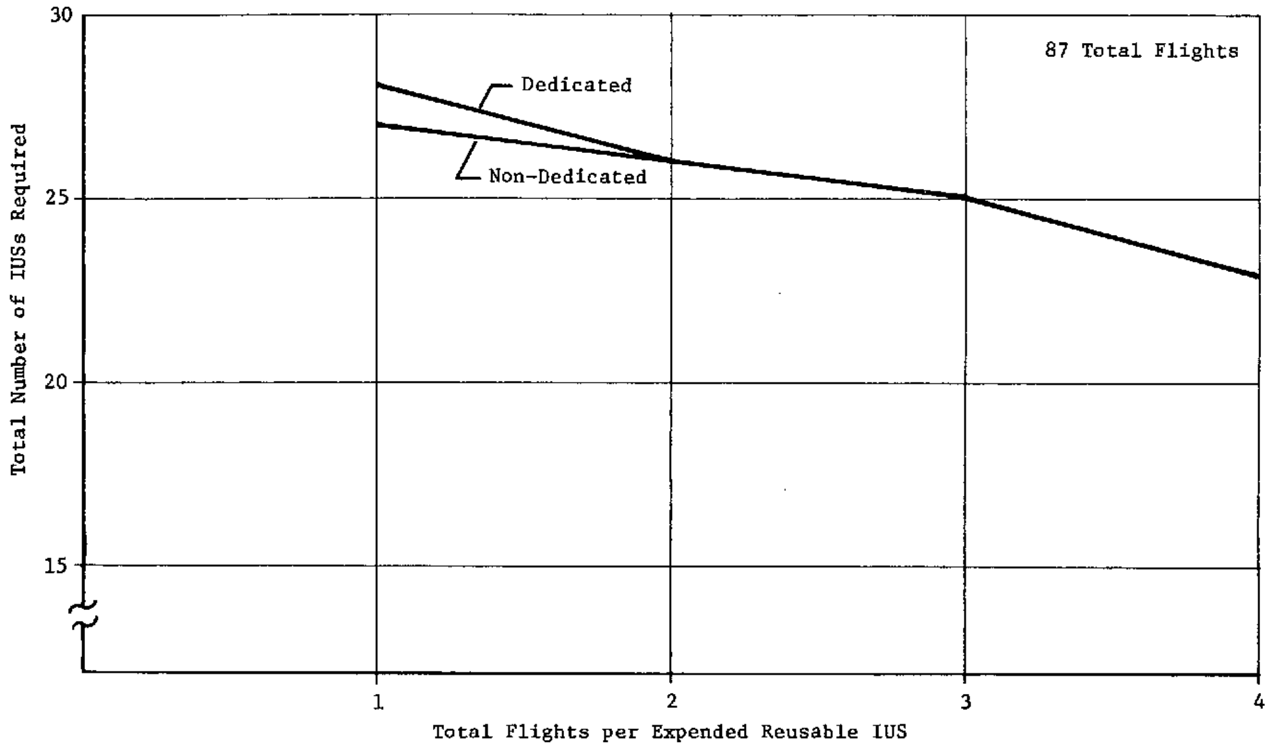

Figure 8-15
Total IUS Requirements, Sensitivity to NASA and DOD Dedicated IUSs

4.5.1 ETR Operations - Maximum Launch Rate - Even Launch Centers - Even Mission Duration

This condition establishes a baseline beyond the single-cycle crew requirements. Figure 8-16 depicts the total operations crew requirements based on the stick-and-ball chart of subplan A to this report. It does show that generally the single-cycle crew requirement will suffice. (The five man over peaks requirement can be eliminated with overtime and spreading the safing cycle over a longer time frame.)

4.5.2 ETR/WTR Operations - Maximum Launch Rate - Even Launch Centers - Even Mission Duration

Figures 8-17 and 8-18 present total operations personnel requirements for ETR and WTR operations. Both figures, one for a one-shift operation and the other for two shifts, indicate a peak requirement of about 62 to 65 people. These numbers have been taken from the ETR stick-and-ball chart of subplan A and the WTR stick and ball chart of subplan B of this report.

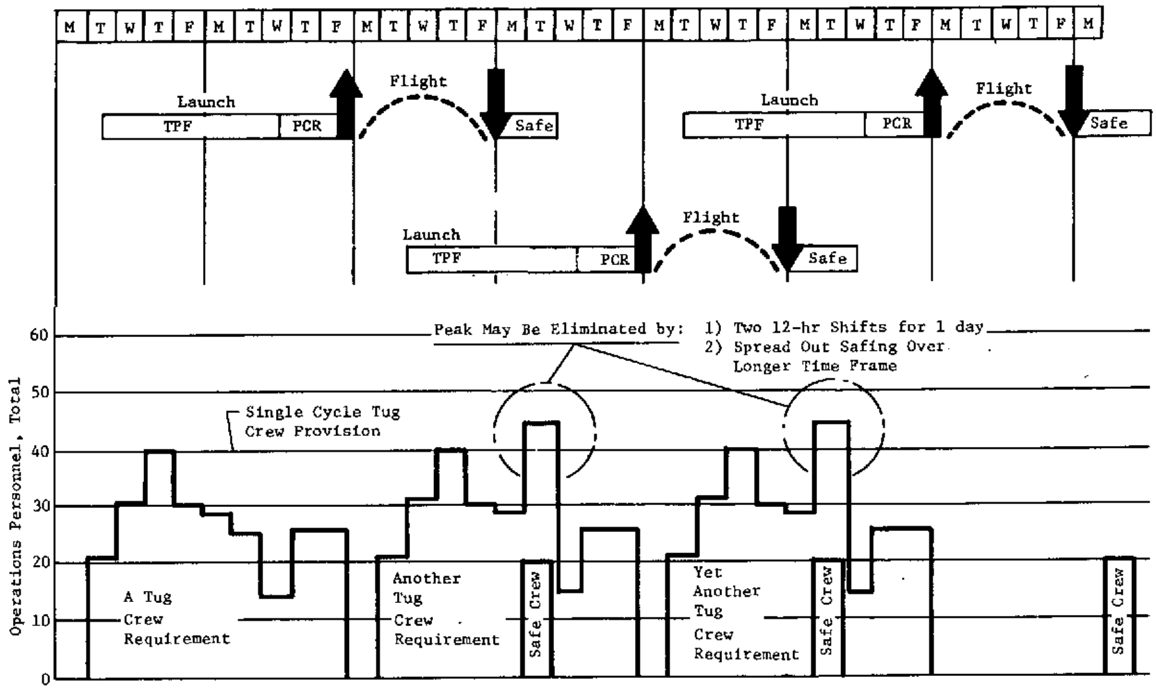

Figure 8-16
ETR Operations, Maximum Launch Rate, Even Launch Centers, Crew Requirements

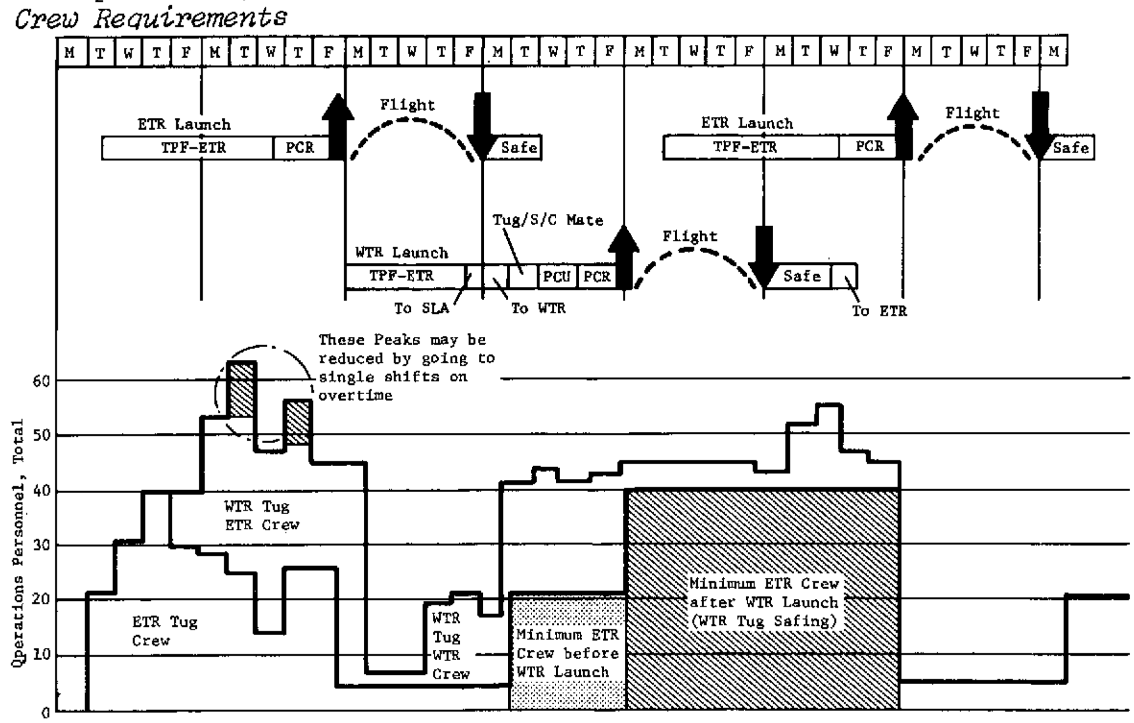

Figure 8-17
ETR/WTR Operations, Maximum Launch Rate, Even Launch Centers, Crew Requirements, One-Shift Operations at WTR

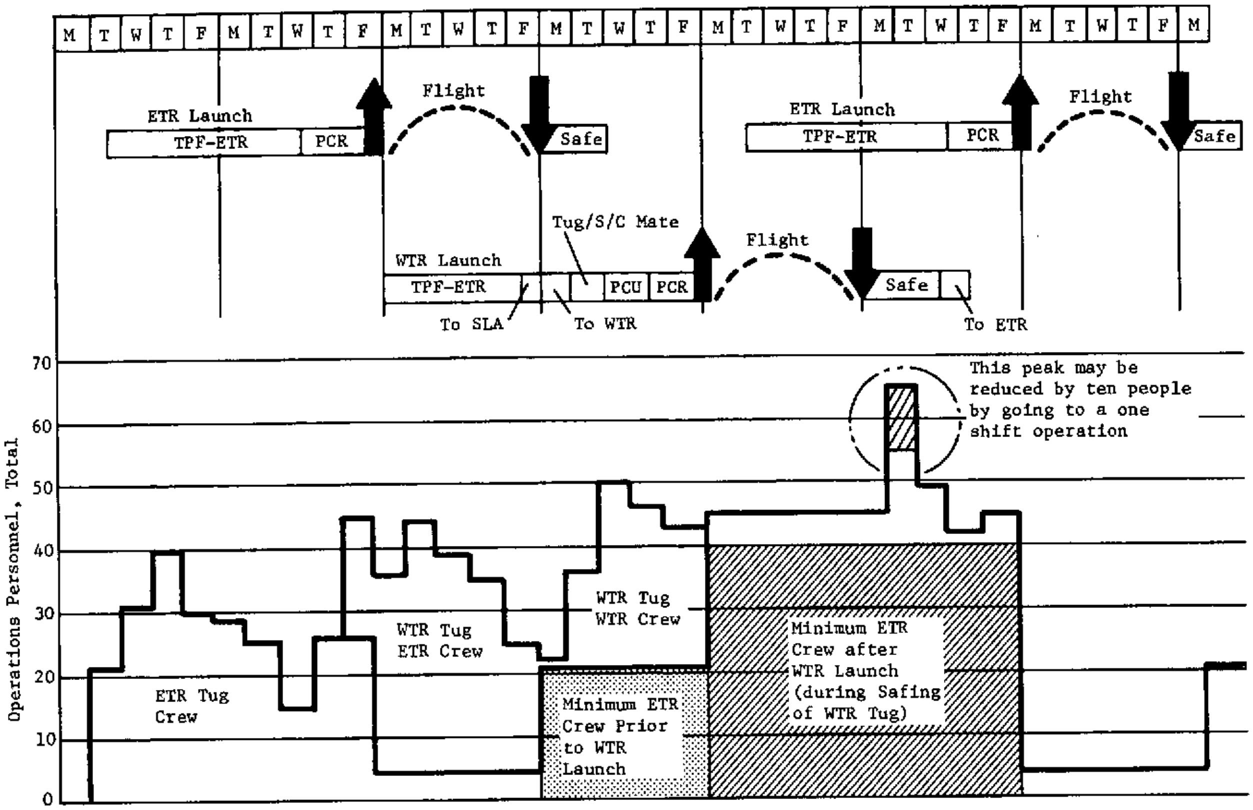

Figure 8-18
ETR/WTR Operations, Maximum Launch Rate, Even Launch Centers, Crew Requirements, Two-Shift Operations at WTR

4.5.3 Uneven Launch Centers

The maximum Tug annual launch rate (26) indicates bi-weekly launch centers on the average; however, over a shorter period launch centers may be closer together. Physical limitations to the facility (two launch pads, with a 5-day refurbish cycle per pad) limit launch centers to a 5-day minimum. The sensitivity of the operations crew size to these uneven launch centers is depicted in Figures 8-19 and 8-20 to indicate the ETR-only crew sensitivity and the ETR/WTR crew sensitivity. These figures show that the ETR/WTR crew can routinely handle uneven launch centers to five days. Figure 8-19 indicates the ability of the basic ETR crew to handle uneven launch centers to five days by going to a seven-day work week with two 12-hour shifts per day (with shift biasing and processing schedule adjustment to eliminate three one-shift-only peaks).

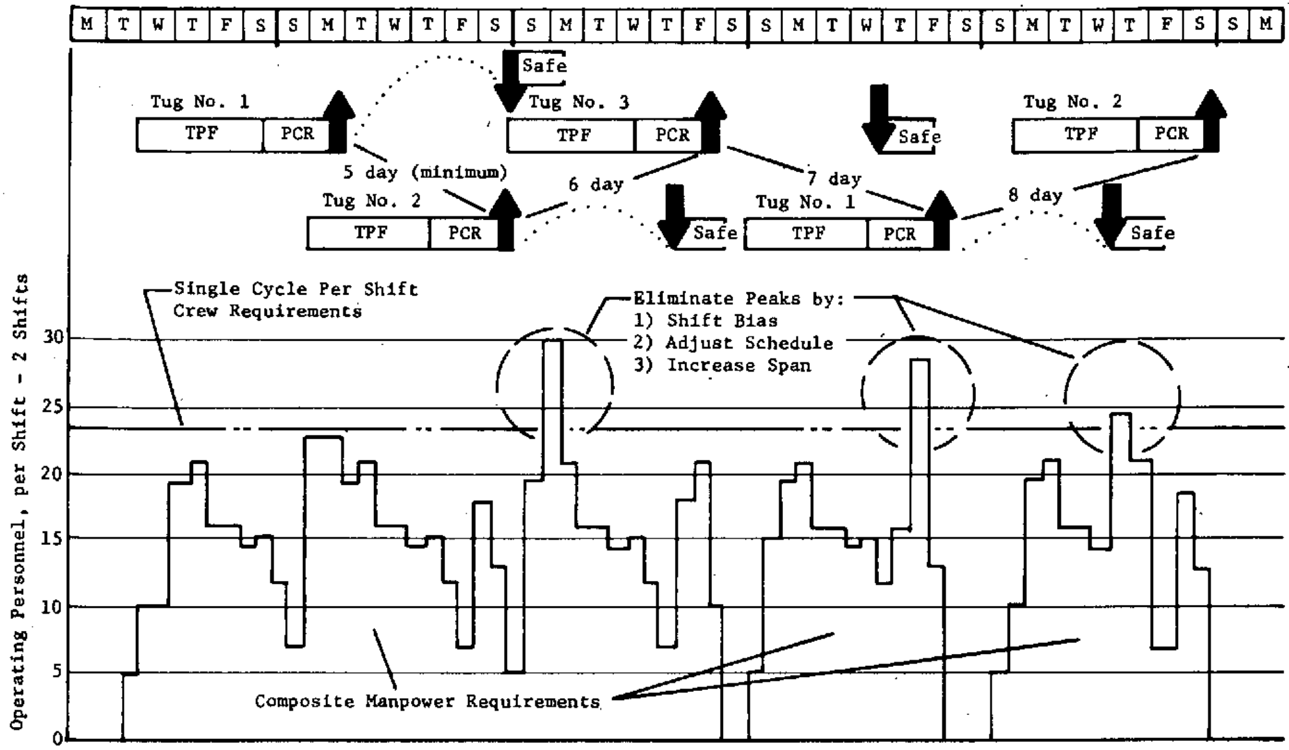

Figure 8-19
ETR Operation, Uneven Launch Centers, Crew Requirements, Two-Shift, Seven Day Week

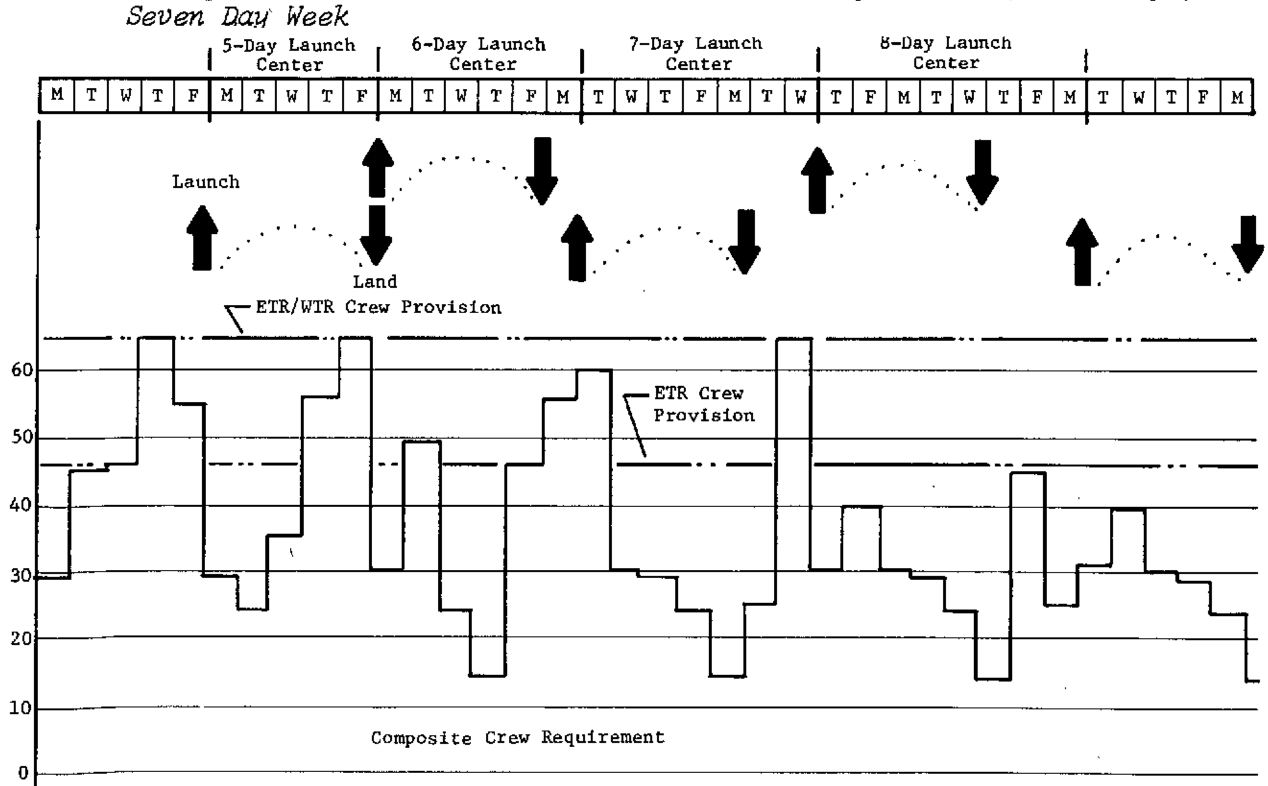

Figure 8-20
ETR Operation Increased Launch Rate, Crew Requirement, Two-Shift, Five-Day Work Week

4.5.4 Uneven Mission Durations

Tug mission durations may vary from one day to seven days imposing a time variable on the safing function after landing. Figure 8-21 shows this variation imposed on the manpower required to process the next Tug (for planning purposes using even launch centers, bi-weekly launches). The ETR/WTR crew can adequately handle all mission durations. The ETR crew can routinely handle all but two, and those can be handled in several ways: (1) overtime, (2) schedule adjustment, (3) time sharing of skills on two Tugs during safing, etc. Therefore: uneven mission durations do not affect crew size.

4.5.5 NASA and DOD Dedicated Crews

If DOD provides dedicated crews for DOD launches, Figure 8-22 depicts the crew requirements. Dedication increases operational crew requirements by about 50%.

4.6 FACILITY SENSITIVITY

Two basic facilities, the launch pad and the TPF test cell, are sensitive to the time span between launch centers in terms of numbers required. Figures 8-23 and 8-24 show this sensitivity. Both figures indicate a probable minimum requirement of one (launch pad and test cell); however, both are marginal in the minimum span of five days between centers indicating two each should be provided.

4.7 GSE SENSITIVITY

GSE requirements are also sensitive to the working days between launch centers and the short-term launch rate. Figure 8-25 depicts sensitivity in terms of percentage of use in time per processing cycle. The figure indicates that, for the most part, the short-term and long-term launch rate can be met with one set of GSE. Only five of the 70 items identified in Appendix B, need to be provided in extra quantities.

4.8 MODULAR TUG CONCEPT - SENSITIVITY OF AVIONICS MODULES

Given a modular Tug consisting of separable avionics and a propulsion module, the number of avionics modules can vary as a function of mission life such that fewer avionics modules may be required than would otherwise be required in a nonmodular Tug. Figure 8-26 indicates this sensitivity. Because of the high number of expendable flights, the reduction in modules as mission life goes up is not as attractive as was expected.

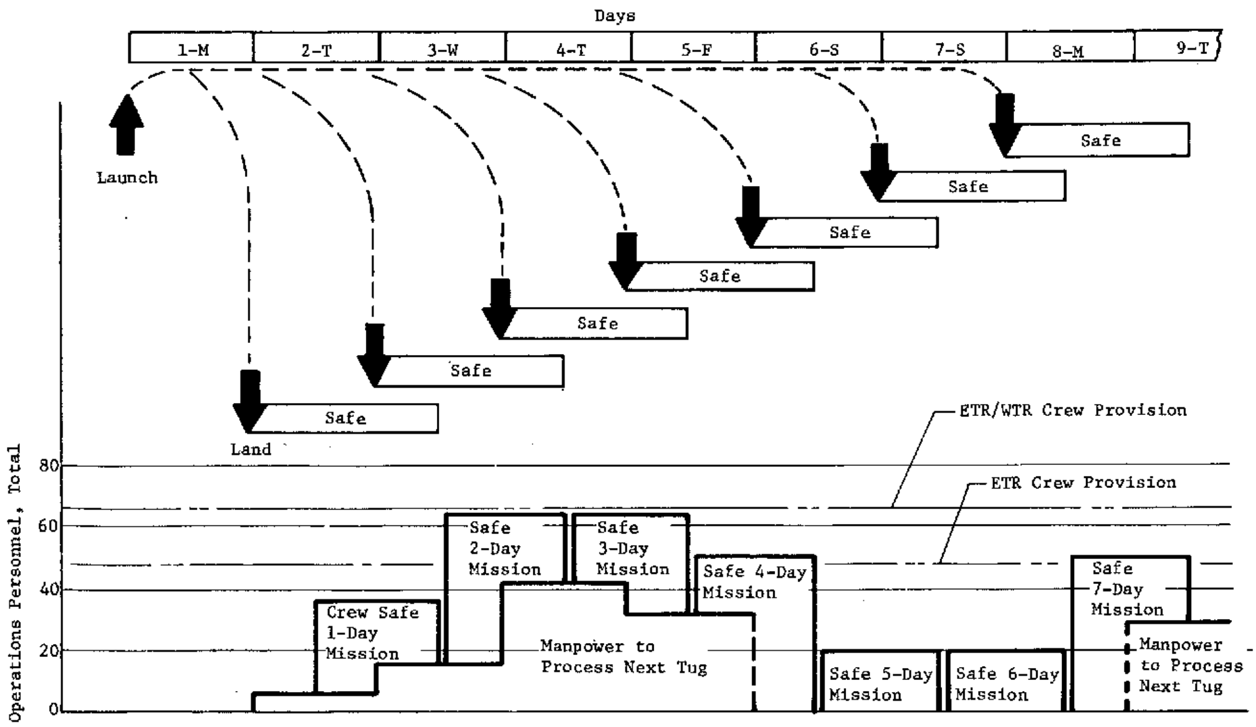

Figure 8-21
ETR Operations, Even Launch Centers, Uneven Mission Duration, Crew Requirements

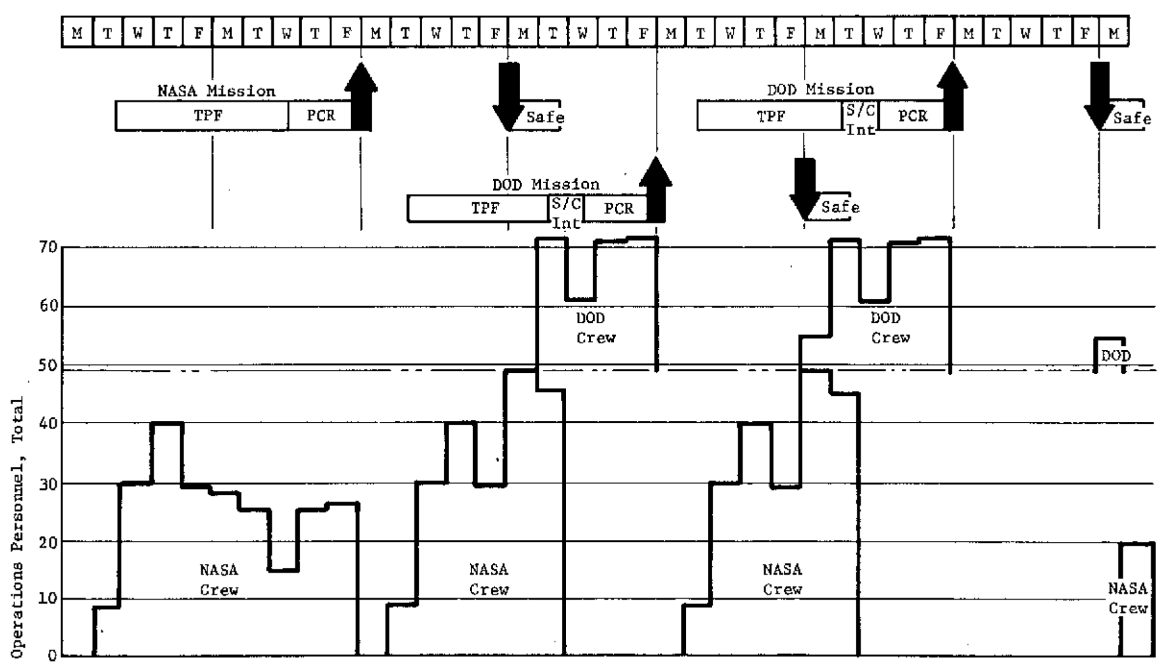

Figure 8-22 ETR Operation, NASA and DOD Dedicated Crews

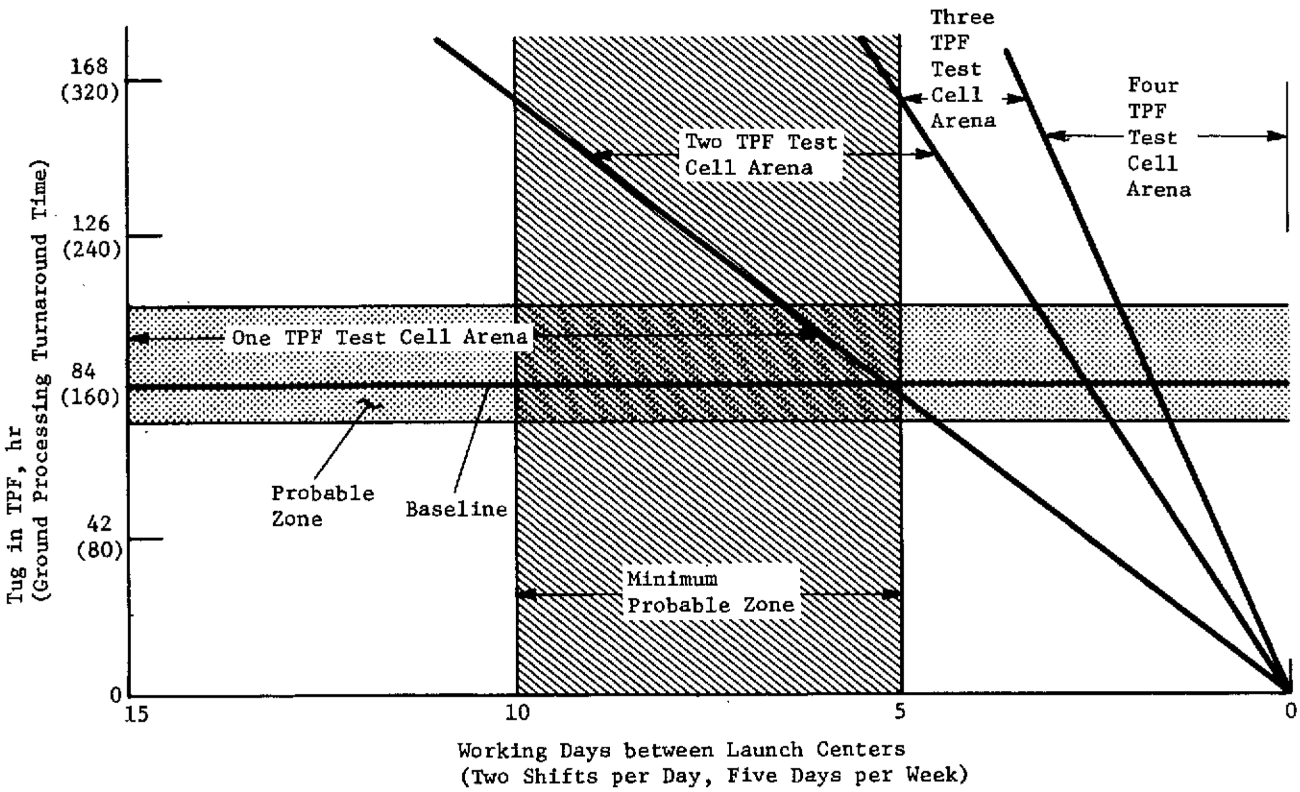

Figure 8-23 Minimum TPF Test Cell Requirements

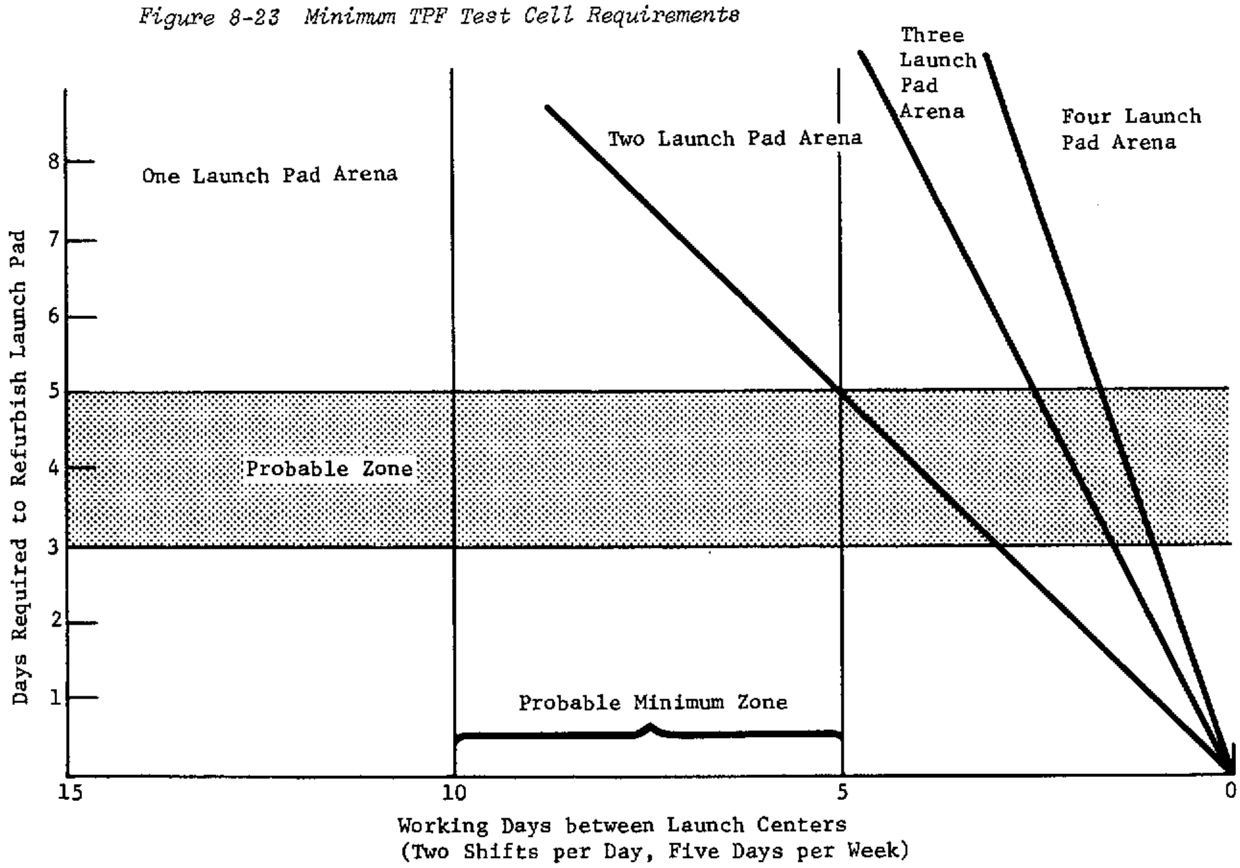

Figure 8-24 Minimum Launch Pad Requirements

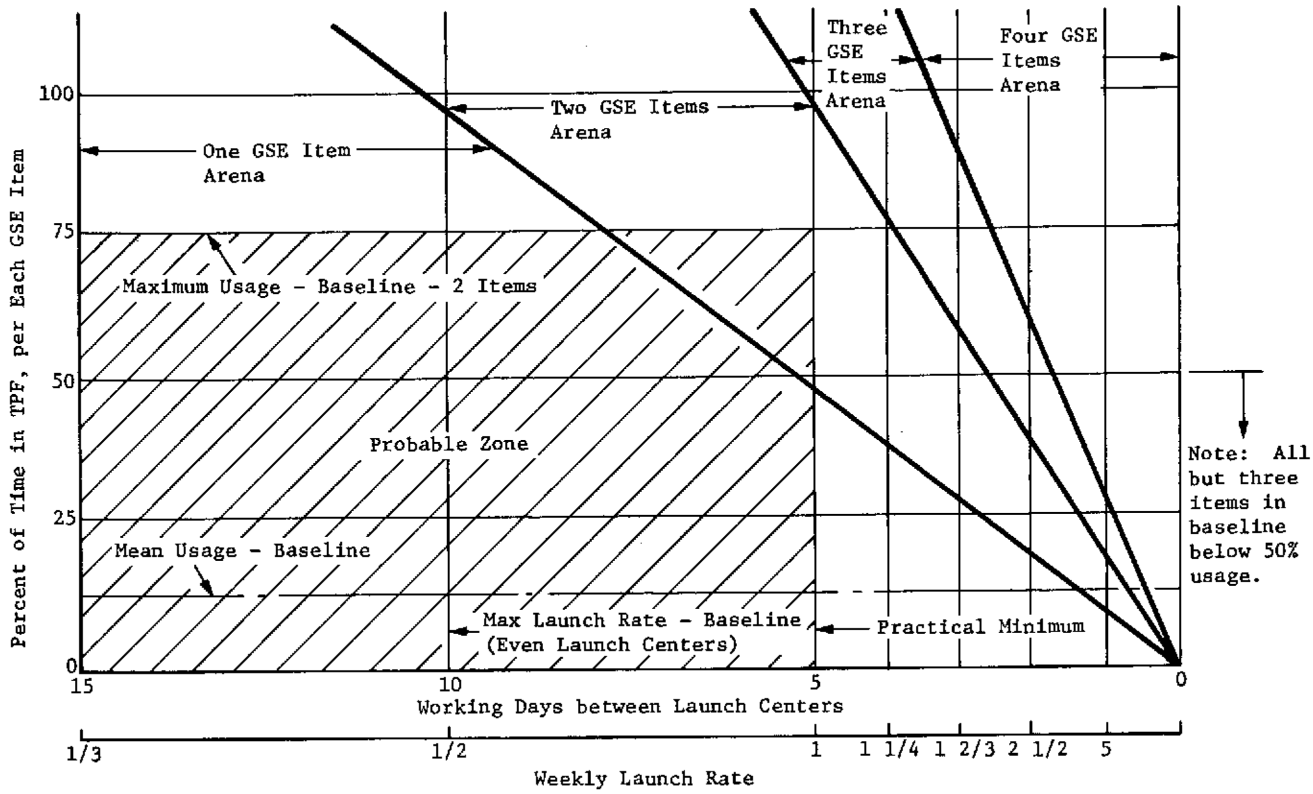

Figure 8-25 Minimum Quantities of GSE and Software to Satisfy Green Light Flow

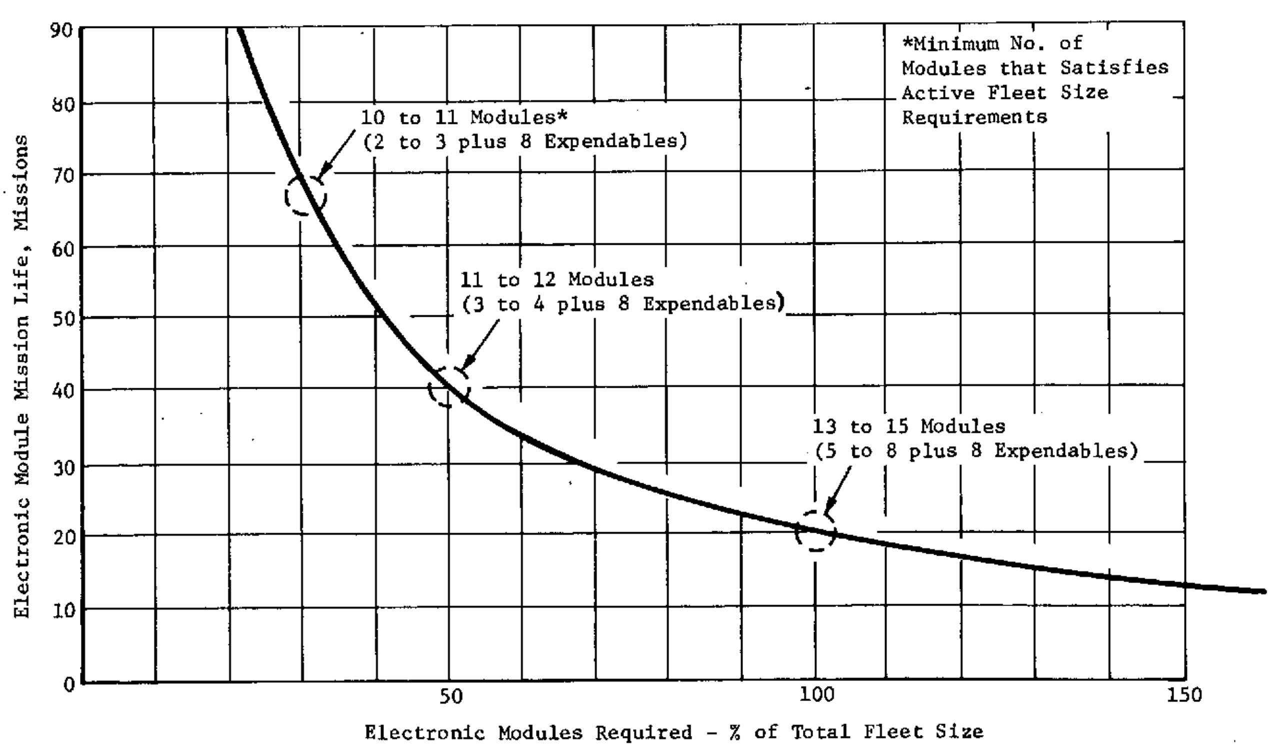

Figure 8-26 Modular Tug Concept, Sensitivity of Avionics Module Requirements

Addendum 9 Vertical vs Horizontal Handling

MCR-74-488
NAS8-31011

Addendum 9 January 1975

TUG VERTICAL VS
HORIZONTAL HANDLING

Prepared by

Jerry J. Gallentine
Test Integration

CONTENTS

Table

1.0 INTRODUCTION

The IUS/Tug orientation (vertical or horizontal) is of prime interest and concern to the ground operations analysis. Orientation affects the facility requirements, GSE requirements, and transportation and handling equipment requirements. Recommended orientation for processing after consideration of these requirements, as well as spacecraft requirements, is presented in this addendum. Spacecraft requirements will be limited to those that affect Tug during and after mating.

This assessment considers Tug requirements for processing and site-to-site transportation requirements.

2.0 GROUND RULES

All elements were analyzed to determine the effect of orientation; only ground operations flow, facilities/GSE, and transportation support equipment were considered to be significantly affected.

In addition to the study elements, the effect of spacecraft requirements during and after mating to the Tug, must be considered.

3.0 SUMMARY OF RESULTS

After analyzing the considerations it is recommended that the IUS and Tug be processed in the vertical position and transported in the horizontal position. However, at this time, it appears that the spacecraft requires vertical transport to the launch pad. This requirement would entail expensive and complicated transportation and handling equipment. As the Tug has no requirement for vertical transport, costs attendant on the vertical transport requirement should not be absorbed by the Tug program.

Some key functions reacting to spacecraft preferences/requirements are (1) Tug-to-spacecraft mate vertically, (2) integrated checkout after mate vertically, and (3) payload-to-Orbiter mate in the vertical orientation.

The IUS would prefer vertical processing because of existing GSE and procedures, while GSE supporting Tug processing has not yet been designed; therefore, orientation has little impact.

4.0 DISCUSSION

Table 9-1 summarizes the preference of the IUS, Tug, and Tug/spacecraft for various phases of the Tug program. A preference for vertical processing, spacecraft mate and checkout, and vertical transport to launch pad is shown in the table. Also indicated is an IUS/Tug-only preference for horizontal transport.

Table 9-1 Vertical vs Horizontal Considerations

Element / Program Phase	GSE			TSE			Facility			Operation Crew		
	IUS	Tug	Tug-S/C	IUS	Tug	Tug-S/C	IUS	Tug	Tug-S/C	IUS	Tug	Tug-S/C
Processing (Tug or IUS only)	V	--	--	V	--	--	V	V	V	V	V	V
Spacecraft Mate and Checkout	V	--	V	V	V	V	V	V	V	V	V	V
Transport to Launch Pad	--	--	--	H	H	V	--	--	--	H	H	H
Transport ETR to WTR	--	--	--	H	H	--	--	--	--	H	H	H
Transport from Manufacturing	--	--	--	H	H	--	--	--	--	H	H	H

V = Vertical Preference

H = Horizontal Preference

-- = Not Applicable or No Preference

4.1 IUS/TUG-ONLY PROCESSING

Tug-only processing does not require either horizontal or vertical positioning. Access would be easier in the horizontal, while some maintenance items could be accomplished more efficiently in vertical orientation. IUS/Tug manufacturing, transport, and landing is in the horizontal position; launch is in the vertical. Tug project prefers all transportation, i.e., contractor to launch site, TPF to launch pad, in the horizontal orientation.

While Tug has no preference for processing in the horizontal or vertical orientation, the IUS does. The IUS prefers vertical processing because of existing GSE and present processing procedures. The IUS, like the Tug, also prefers all transportation in the horizontal.

4.2 SPACECRAFT CONSIDERATIONS

A review of SSPD data reveals that at this time there is insufficient data to determine Shuttle era post-Tug mating handling requirements. In lieu of Shuttle era spacecraft data, a survey was made of existing spacecraft mating preferences. Table 9-2 shows the results of that survey. It can be seen that all spacecraft currently flying and all other spacecraft considered prefer mating in the vertical position. In addition to the preferences, there were four spacecraft that required vertical mating. These requirements are as follows: (1) bubble entrapment in the hydrazine system (no bladder expulsion); (2) "fines" from the catalyst bed migrating out to thrusters if handled horizontally; (3) a sun shade that cannot be handled horizontally because it cannot support itself in a 1-g environment; and (4) a long cylindrical solar array on long booms that cannot be handled horizontally. This survey was based on some customizing of existing spacecraft to fly on Tug. None of these conditions changed the requirements for vertical handling. With considerable redesign, the above problems might be solved.

4.3 OPERATIONS CREW

Crew size is not affected by orientation of the vehicle. The operations to be accomplished are the same in either orientation, and with proper design, access will not be a problem.

At present and in the past, all launch site processing crew experience has been to process in the vertical orientation. As the IUS prefers vertical processing, the crew transition from IUS to Tug requires less training if both the IUS and Tug were processed in the same orientation.

4.4 GSE/FACILITIES

The IUS prefers vertical processing because of existing GSE and processing procedures. Because the Tug GSE has not been designed, orientation would cause minimal impact on the Tug GSE. One area that would be affected would be spacecraft mate with Tug. This mating would be less complicated if accomplished in the vertical, and would require less complicated GSE, particularly alignment equipment. Vertical processing would require the SAEF-1 airlock to be modified by raising the roof, and a manipulator would be required to insert the Tug/spacecraft into the payload canister. Subplan D recommends activating the VAB low bay. Orientation has minimal effect on the VAB low bay, and the recommended approach of handling the vertical payload would not require a manipulator for loading. Horizontal processing would require more floor space compared to vertical processing.

Table 9-2 Vertical vs Horizontal Processing - Spacecraft to Tug Mating

Spacecraft	Currently Flying	Current Mating Operations		Preferred Mating Operations		Mandatory Mating Operations	
		Horiz	Vert	Horiz	Vert	Horiz	Vert
1 ATS	X		X		X		X
2 CSC	X		X		X		
3 SEOS					X		
4 ATS-EXP					X		
5 CSC-EXP					X		
6 SEOS-EXP					X		
7 AGOES					X		
8 SMS	X		X		X		
9 MJS	X		X		X		
10 DSCS	X		X		X		X
11 FSC	X		X		X		
12 DSP	X		X		X		X
13 DSCS-S					X		
14 DSP-S					X		X

Considerations:

1. All currently flying spacecraft are mated to carrier in vertical position.
2. All spacecraft surveyed prefer mating in vertical position.
3. At least four of the spacecraft surveyed require mating in vertical position.

4.5 TRANSPORTATION SUPPORT EQUIPMENT

Spacecraft mate at the TPF drives the decision for vertical integration, checkout, and transfer from TPF to PCR. Before spacecraft integration, there is no requirement for vertical orientation of IUS, Tug, or kick stage, although IUS prefers vertical orientation based on existing GSE and its support documentation. Manufacturing operations, air transport, ground movement, and handling to the point of integration favors horizontal orientation. IUS, Tug and kick stage favor horizontal orientation throughout the handling process. The TPF vertical pivoting operation and need for a pivoting adapter can be avoided. Crane operation can handle intra-TPF moves and transporter on/off loadings without the requirement for a manipulation device. Tug design is not affected by manipulation pad loadings. Horizontal positioning facilitates access for payload to canister loading and internal attachment. A canister cover can best be accessed, removed, handled, and installed in the horizontal position. Canister and canister transporter design and development costs are reduced if vertical tip-over control for wind and accelerations and horizontal to vertical erection/stabilization are not required. Ramp slope to attain PCR loading postion on pad is a problem for vertical transport.